FEASIBILITY OF FUNCTIONAL FIBERS IN SOY CHICKEN NUGGETS

A Thesis

by

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ABSTRACT

Soluble fiber in diet provides many health benefits; however, most people in the U.S. have much less than the daily value of fiber. Therefore, the objective of this study was to develop a soy protein chicken nugget with added functional fibers to meat block to increase dietary fiber intake. Soy chicken nuggets were made with an industry soy formulation (30% of meat block weight replaced by pre-hydrated 3:1, wt/wt water: textured soy protein concentrate with added 10% brine resulting in 0.60% salt and 0.50% phosphates of final product). Treated nuggets were formulated to add 3.0 g of functional fibers (70% isomalto-oligosaccharide (IMO) and 30% hydroxypropyl methylcellulose (HPMC)) per serving (3 nuggets, 87 g) based on the control formula. The control and treatment were evaluated for pick-up (%), par-fry yield (%), cook loss (%), frozen loss (%), final yield (%), color (L*, a* and b* value), shear force and fiber contents (total dietary fiber (TDF), soluble dietary fiber (SDF) and insoluble dietary fiber (IDF)). All data were analyzed by SAS 9.3, using ANOVA and significance was determined using a P value of < 0.05. The results indicated that treatment nuggets had lower par-fry yield (%) and freeze loss (%) ($P < 0.05$) compared with control, but no difference ($P > 0.05$) in pick-up (%), cook loss (%) and final yield (%). Also the addition of fiber to the treatment resulted in lower L* (darker color), higher b* value (more yellowness) and more tender texture ($P < 0.05$). Treatment nuggets contained 2.91 g TDF per serving, claimed as a "Good Source" of fiber, but the results of fiber content were much lower than the supplementation level in formula by both Association of Official Analytical

Chemists (AOAC) Official Methods 985.25 and 991.43 and AOAC Official Methods 2009.01 and 2011.25, due to the limitation of these methods. In conclusion, functional fibers has the potential to be incorporated in the meat block to produce a fiber-added soy chicken nuggets, but more reliable fiber methods need be developed for determining the fiber contents in meat products.

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NOMENCLATURE

AK	Allo-Kramer
AOAC	Association of Official Analytical Chemists
ANOVA	Analysis of Variance
CFR	Code of Federal Regulations
CHD	Coronary Heart Disease
CIE	Commission International de l'Eclarirage
CIELAB	CIE L*a*b*
CoA	Coenzyme A
d	Day
DV	Daily Value
HDL	High-density Lipoprotein
HMWDF	High Molecular Weight Dietary Fiber
HPLC	High Performance Liquid Chromatographic
HPMC	Hydroxypropyl Methylcellulose
hr	Hour
IDF	Insoluble Dietary Fiber
IMO	Isomalto-oligosaccharide
LDL	Low-density Lipoprotein
LMWSDF	Low Molecular Weight Soluble Dietary Fiber
MC	Methylcellulose

MFG	Methylcellulose Food Gums
min	Minute
pI	Isoelectric Point
pH	Hydrogen Potential
RS	Resistant starch
SAS	Statistical Analysis System
SDF	Soluble Dietary Fiber
SDFP	Soluble Dietary Fiber Precipitate
SDFS	Nonprecipitable Water: Alcohol Soluble Dietary Fiber
sec	Seconds
SSF	Slice Shear Force
STP	Sodium Triphosphate
TDF	Total Dietary Fiber
TSPC	Textured Soy Protein Concentrates
USDA	United States Department of Agriculture
USDA-FSIS	United States Department of Agriculture Food Safety and Inspection Service
WB	Warner Bratzler
WHC	Water Holding Capacity
w/w	Weight over Weight

TABLE OF CONTENTS

Page

ABSTRACT ii

ACKNOWLEDGEMENTS iv

NOMENCLATURE v

TABLE OF CONTENTS vii

LIST OF FIGURES ix

LIST OF TABLES x

CHAPTER I INTRODUCTION AND LITERATURE REVIEW 1

Introduction 1
Literature Review 3
Ingredients 3
Chicken nugget preparation 20
Meat qualitative analysis 25

CHAPTER II EVALUATION OF SOY CHICKEN NUGGETS 36

Introduction 36
Materials and Methods 39
Soy chicken nuggets preparation 39
Color evaluation 42
Shear force 43
Fiber content 43
Statistical analysis 44
Results and Discussion 44
Yield parameters 44
Color evaluation 52
Shear force 55
Fiber content 56

CHAPTER III CONCLUSIONS 66

REFERENCES 68

Page

APPENDIX A PRELIMINARY EXPERIMENTS 79

LIST OF FIGURES

Page

Figure 1. Basic Procedures of AOAC Official Methods 985.29 and 991.43 32

Figure 2. Basic Procedures of AOAC Official Methods 2009.01 and 2011.25 33

LIST OF TABLES

Page

Table 1. Chicken Nugget Meat Block Formulations Used for Manufacturing the Control and Fiber-added Soy Chicken Nuggets 39

Table 2. Mean and Standard Deviation of Yield Parameters Measured on Control and Fiber-added Soy Chicken Nuggets. 45

Table 3. Mean and Standard Deviation of CIELAB Color Space Values on Control and Fiber-added Soy Chicken Nuggets Meat Block..... 52

Table 4. Mean and Standard Deviation in Shear Force of Control and Fiber-added Soy Chicken Nuggets 54

Table 5. Fiber Content of Control and Fiber-added Soy Chicken Nuggets Measured by AOAC Official Methods 985.25 and 991.43 and AOAC Official Methods 2009.01 and 2011.25..... 57

Table 6. Fiber Content of Control and Fiber-added Soy Chicken Nuggets Measured by AOAC Official Methods 2009.01 and 2011.25..... 60

Table 7. Fiber Content of HPMC Product, IMO Product and Blank Treatment Nuggets Measured by AOAC Official Methods 2009.01 and 2011.25..... 62

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

Chicken nuggets are a popular fried food for children. Fried foods are categorized as junk food since they have a high energy density due to the increased fat and calories (Fillion and Henry, 1998). Some studies have indicated that consumption of fried foods can contribute to the increased risk for diseases such as diabetes, obesity, cardiovascular diseases, and cancers (Stender et al., 2007).

Functional fiber consists of isolated and indigestible carbohydrates that have beneficial physiological effects in humans (Institute of Medicine, 2004). The daily recommended intake of dietary fiber can reduce the risk for developing cardiovascular diseases (Lairon et al., 2005; Liu et al., 1999), diabetes (Montonen et al., 2003), obesity (Van Itallie, 1978), and certain gastrointestinal diseases (Petruzziello et al., 2006). Additionally, an increased consumption of dietary fiber, can reduce LDL-cholesterol level, reduce blood pressure, control blood glucose, aid in weight loss, and improve bowel regularity (Anderson et al., 2009). Soluble fibers, which can be dissolved in water, such as psyllium, pectin, and oats, have the function of reducing total and low-density lipoprotein (LDL) cholesterol in human (Brown et al., 1999)

Due to the low consumption of vegetable, fruit, and whole-grain food in the average human diet (Clemens et al., 2012), the mean dietary fiber intake for people 2 years and older, in the USA, is 16 g per day (Holy and Goldman, 2014). This is much

lower than a recommended Daily Value (DV) intake of dietary fiber that is 25 g for adults and children of 4 or more years old according to 21 Code of Federal Regulations (CFR) part 101 (FDA, 2015). One of the most popular chicken nuggets for children and adults, Chicken McNuggets™ from McDonalds™, has a single serving size of 4 nuggets (65 g) which contains 1 g of dietary fiber content (McDonald's Corporation, 2014). For other commercial chicken nuggets from fast food restaurants such as Burger King, Wendy's, and Tyson, the nutritional facts indicate that the similar one serving of chicken nuggets has similar fiber content as McDonalds (Burger King Corporation, 2015; The Wendy's Company, 2015; Tyson Foods Incorporation, 2014). Due to the low fiber intake of consumers in the USA and the low fiber content of chicken nuggets, functional fibers could be introduced into chicken nugget's formulas to increase the consumer's overall fiber intake.

The study was focused on developing a soy chicken nugget containing functional fibers in the meat block with the intent of increasing the availability of dietary fiber for consumers, mainly children. The target of fiber supplementation was to achieve more than 2.5 g of fiber per serving, which allows for the claim of a "Good Source" of fiber. Fiber-enriched soy chicken nuggets were produced to evaluate the effects on yield, color, texture, and fiber content compared with that of the control, soy chicken nuggets.

Literature Review

Ingredients

Meat

Comprehending the ultrastructure and composition of the muscle is important in order to understand the functional interactions within meat products. The muscle fiber is a conglomerated of myofibrils held together in groups known as fascicles, which in turn conform fiber bundles that form specific muscles. The myofibrils, fascicles and fiber bundles are covered by connective tissue (endomysium, perimysium, and epimysium; respectively). The myofibril is the basic unit of the muscle fiber cell which is organized into contractile segments known as sarcomeres, which have myofilaments consisting of thick and thin filaments. Each sarcomere can be separated into the A-band containing thick and thin filaments, and the I-band containing thin filaments only. The myofibrillar filaments represent ~50-56% of the total proteins in the muscle (Barbut, 2001). The two major kinds of myofibrillar proteins are myosin (thick filament) and actin (thin filament). Other proteins are present in the muscle, these include sarcoplasmic (hemoglobin, enzymes, other cell organelles; ~35%) and stromal (connective tissue; ~3-5%) protein (Barbut, 2001). However, in order for muscle to become meat or for these proteins used to develop products and consumed, the onset and resolution of rigor mortis must occur. During the development of rigor mortis, the actomyosin bonds are created during involuntary muscle contraction and lack of adenosine triphosphate (ATP). As rigor mortis continues and is resolved, muscle pH declines (~5.8-6.0 pH) from the increase of

lactic acid and the actomyosin bonds cleaves to allow the muscle to enter a relaxed state (Barbut, 2001).

In the processing of broiler meat two types of meat need consideration, so called white and dark meat. White meat comprises meat obtained from the breast and tender meat cuts. This meat has a low hemoglobin, fat, and connective tissue content; and by contrast high amounts of protein. Dark meat is obtained from muscles involved in motor functions. This meat has greater amounts of hemoglobin, fat, connective tissue, and lower protein content compared with white meat. According to USDA Agricultural Research Service (2015), boneless and skinless broiler breast meat contained 22.50% protein and 2.62% fat, while boneless and skinless dark meat had 19.66% protein and 4.12% fat content.

The meat sources used in the manufacturing of chicken nuggets can be whole boneless and skinless breast meat chunks, tenders, ground white meat, boneless skinless dark meat chunks, and ground dark meat, with or without adding mechanically deboned meat and skin. The meat sources can be different depending on the regions due to the preferences. For example, in Asia dark meat is preferred over white meat as a result the dark meat has a higher economic value, while in the USA white meat is mostly used in nuggets and has a higher economic value (Owens, 2001). The addition of mechanically deboned meat chicken and skin can increase the fat content allowing for more flavors, and lower the overall cost.

However, the high fat content of chicken nuggets reduces the shelf-life because unsaturated chicken fat is more susceptible to oxidation. This lipid oxidation causes the

undesirable change in color and flavor of meat products. A visual indicator is seen through the ferric heme pigments as they are the major prooxidants that activate lipid peroxides by iron ions (Love and Pearson, 1971). Sodium chloride is also a lipid prooxidant as sodium can displace the iron ions chelated by protein and increase the concentration of free iron ions, thereby allowing oxidation via ferrous ion (Kanner et al., 1991). Phosphates can be used as an antioxidant to inhibit lipid oxidation by chelating the prooxidants, metal ions such as ferrous (Fe^{2+}) iron (Stoick et al., 1991).

Salt

Salt is a functional ingredient to help water-binding activity and improve overall quality in the chicken nuggets. Salt can also increase the flavor intensity while improving the savory flavor in a meat product. Salt, primarily sodium chloride (NaCl), is easily solubilized in water and dissociates into Na^+ and Cl^- ions. Potassium chloride can be a substitute for sodium chloride to reduce the overall sodium content in low-salt labeled products. Generally, salt concentration is smaller than 1% for the final meat product (Owens et al., 2010), due to salt being a flavor self-limiting ingredient.

The addition of salt ions also enhances ionic strength. Na^+ and Cl^- ions can bind to the side chains within salt-soluble meat proteins while separating the side chains. This causes an increase in the extraction of proteins (Feiner, 2006). Additionally, the myosin and actin, mentioned earlier, can be solubilized in a salt solution by reducing the electrostatic forces among proteins, which leads to the fracture of myofibril structure and the extraction of myofibrillar protein. Xiong et al. (2000) reported that the extraction of the protein from chicken myofibrils was noticeable by reduction in the A-band intensity

when the NaCl concentration increased to 0.6 M. The myofibrillar proteins that are extracted by salt solution can bind more water by swelling and increase the water holding capacity (WHC) of meat by protein-water interaction, increasing the juiciness for final products.

Phosphates

Phosphates are another functional ingredient used in many meat products to increase water binding and improve flavor and texture. Salt and phosphates are usually used in combination as brine for meat application, dissolving phosphate first followed by salt to prevent the precipitation of phosphates. Several forms of phosphates are used such as monophosphate, diphosphate, triphosphate, and polyphosphate. These each differ from one another based on the number of phosphate atoms in the molecule and the chain length. The phosphates with low degree of polymerization, especially diphosphate, are more functional for the purpose of increasing WHC in meat, but their application is limited due to low and slow solubility. While triphosphate could be soluble in water, but its effects of WHC is slow due to the conversion to diphosphate by hydrolysis (Dušek et al., 2003). Due to the different functionality discrepancies of each phosphate, the blending of different polyphosphates is commonly used in meat processing.

Phosphates are a United States Department of Agriculture Food Safety and Inspection Service (USDA-FSIS) regulated ingredient with a limit of no more than 0.5% in the final product (Smith and Hong-Shum, 2011). This limitation is based on product quality, due to the restrictions of water addition to products as well as off-flavor (soapy) problems caused by usage above 0.5% (Barbut, 2001).

Phosphates can increase the solubility of myofibrillar proteins by reducing the electrostatic forces within the actomyosin complex. They can also break down the actomyosin bond allowing the separation of myosin and actin after rigor mortis by chelating the negative ions of phosphates and positive ions Ca^{2+} and Mg^{2+} (Feiner, 2006). The Ca^{2+} cation induces the binding between myosin and actin during the muscle contraction. In addition, phosphate as an acid salt, especially sodium triphosphate (STP), can increase the pH of meat product by the hydrolysis of phosphate groups. Isoelectric point (pI) is the pH at which a molecule doesn't have any net electric charge. The pH of chicken meat is ~5.8-6.0 after rigor mortis, which is higher than the isoelectric point of myosin (pI=5.3) and actin (pI=4.7) (Barbut, 2001). This indicates that the charge of myofibrillar proteins is negative in the meat. Increasing the pH, away from the isoelectric point of the myofibrillar proteins, allows the release of more negative binding sites for water, which increases the WHC of meat.

Textured soy protein concentrates (TSPC)

Non-meat proteins such as soy, dairy, and pea proteins have been applied as extenders in meat products, which can significantly reduce the cost and the overall price to consumers. Soy protein products can be classified as flours, concentrates and isolates, depending upon their protein content. Soy protein products are made from dehulling, flaking, and defatting soybeans by method of hexane extraction (Lusas and Riaz, 1995). These defatted beans are milled into the flours containing 50% protein. To increase the protein content, flavor and sugar compounds are removed by ethanol or acidic water to

produce a soy concentrate containing 70% protein. Finally, alkali extraction of proteins can be used to produce the soy isolates with 90% protein (Lusas and Riaz, 1995).

Once the soy proteins are produced from soy protein flours, concentrates, or isolates, they are extruded to create the similar structure of meat protein. The protein materials are forced through a die, which can make the desired size and shape of textured soy proteins (Horan, 1974). This extrusion process causes some denaturation of the soy proteins, which helps to produce a meat-like structure, allowing it to be an excellent meat replacer (Lusas and Riaz, 1995).

Textured soy protein concentrates are a lower-cost and intermediate-flavor product when compared with soy isolates. They are a popular meat replacer to bind water, stabilize fat emulsions, and contribute to the meat-like texture in the meat products (Kinsella, 1979; Lusas and Riaz, 1995). Generally the hydration rate of TSPC is 3:1 (water weight: TSPC weight) in the meat application (Applewhite, 1989). In addition, TSPC are used in foods prepared for the national school lunch program (Lusas and Riaz, 1995). Chicken nuggets produced for this program are allowed up to 30% soy protein product for the meat or meat alternate component of food-based menu, because higher than 30% vegetable protein may inhibit the absorption of iron and other nutrients (USDA, 2012).

Fiber

Dietary fiber is defined as indigestible carbohydrates and lignin that are intrinsic and intact in plants; functional fiber is isolated, indigestible carbohydrates that have beneficial physiological effects in humans (Institute of Medicine, 2004). Total fiber is

the sum of dietary fiber and functional fiber. According to 21 CFR part 101 (FDA, 2015), a recommended DV intake of dietary fiber is 25 g for adults and children of 4 or more years old. For nutrition labeling, a "High Source" claims indicates 20% or more of the DV per serving, and a "Good Source" is defined as a 10% to 19% of the DV per serving. Therefore, 2.5 to 4.9 g of fiber per serving of chicken nuggets could be claimed a "Good Source" of fiber.

Dietary fiber contains two components: soluble and insoluble fiber. Soluble fiber, such as oats, psyllium, pectin, and guar gum, can be solubilized in water. Soluble fibers have been proved to reduce total and low-density lipoprotein (LDL) cholesterol (Brown et al., 1999). Lipoproteins are classified as LDL and high-density lipoprotein (HDL). The LDL cholesterol can aggregate in the walls of blood vessels, causing atherosclerosis and increasing the risk of coronary heart disease (CHD); while HDL cholesterol can scavenge and transport cholesterol to the liver for reprocessing, reducing the risk of CHD (Fernandez and Webb, 2008). Brown et al. (1999) stated that various soluble fibers lowered cholesterol by similar amounts and the differences among lowering-cholesterol effects of different soluble fibers were small in practical range of intake. Anderson et al. (2009) reviewed the publications about the effects of soluble fiber intake on serum LDL-cholesterol level in randomized controlled clinical trials with weighted mean changes. It summarized that an average 10.6% reduction of LDL-cholesterol values for 15 g per day of guar gum, 13% reduction for 15 g per day of pectin, 11.1% reduction for 5 g per day of barley β-glucan and 8.5% reduction for 5 g per day of hydroxypropyl methylcellulose (HPMC). Davidson et al. (1996) studied the cholesterol-lowering effect by psyllium-

enriched cereal in children with hypercholesterolemia. The results of this study indicated that the consumption of psyllium-enriched cereal (6.4 g psyllium per day) reduced LDL-cholesterol level by 7% when compared with the control cereal. The cholesterol-lowering effects of dietary fibers are highly influenced by the viscosity of the fiber. In a study by Gallaher et al. (1993), hamsters were fed for 3 weeks with diets containing four preparations of HPMC varied in viscosity. A linear relationship was found between cholesterol level and the logarithm of intestinal contents supernatant viscosity and it was suggested that increasing the viscosity of intestine contents could be more effective at lowering cholesterol. Other soluble fibers at higher viscosity, such as psyllium and β-glucan from oats, were also found more effective at reducing cholesterol level (Davidson et al., 1991; Davidson et al., 1996). However, the mechanisms for this lowering of cholesterol are not fully established (Theuwissen and Mensink, 2008). A possible explanation of the cholesterol-lowering effect is soluble fibers may form a viscous matrix in the small intestine, interfering with bile acid and cholesterol absorption (Eastwood and Morris, 1992). Another possible mechanism describes the water-soluble fibers, which are fermented by colonic bacteria to produce short fatty acids (propionate, acetate and butyrate) in the intestine, can influence the lipid metabolism by increasing propionate: acetate ratio (Theuwissen and Mensink, 2008). Acetate is a preferred substrate for hepatic cholesterol synthesis, and propionate can reduce cholesterol synthesis by inhibiting the formation of acetyl-Coenzyme A (CoA) which is a substrate in cholesterol synthesis (Wolever et al., 1996), so propionate: acetate ratio could be negatively correlated with serum cholesterol level.

Some recent research reported that approved and available commercial dietary fiber products, such as concentrates from cereals, fruits and vegetables, could be added as extenders in meat products to increase health benefits (Verma and Banerjee, 2010). However, very few studies involving fiber added to chicken nuggets have been reported. Prinyawiwatkul et al. (1997) used flours processed from fermented cowpeas and fermented partially defatted peanuts as meat extenders for chicken nuggets. The results of this study indicated that shear force was decreased, indicating a more tender product when fermented partially defatted peanuts were used. Both extended nuggets had a higher a* (more red), and lower L*(darker color) and b* (less yellow) values. However, the undesirable flavors such as raw-beany flavor, was unacceptable when nuggets were extended at 20% for both flour products. It was concluded that the texture, flavor, and overall liking was acceptable for the chicken nuggets containing 5% of these flour products. Singh et al. (2008) incorporated roasted pea flour into chicken nuggets. The results showed that up to 10% inclusion level could reduce the shear force, moisture, protein, and fat percent, additionally the sensory rating was similar to control product. In another study by Verma et al. (2009), three different combinations of pea hull flour, gram hull flour, apple pulp, and bottle gourd were added at 10% into the chicken nuggets formulation. The results indicated that the addition of these fiber sources significantly increased the dietary fiber content (6.03%, 4.99% and 5.12%) compared with control (0.87%). In a similar study by Verma et al. (2010), apple pulp was incorporated at 8-12% level of chicken nuggets, which significantly increased the dietary fiber content (1.79-

2.45g/100g), a* value (more red) and b* value (more yellow) but decreased the shear force and texture and overall acceptability for the sensory evaluation.

Hydroxypropyl methylcellulose (HPMC)

Hydroxypropyl methylcellulose is a cellulose derivative, which is soluble in water. Structurally, HPMC is a β-1, 4 glucose polymer with the substitution of methyl and hydroxypropyl groups for the hydroxyl groups of cellulose, which breaks down the hydrogen bonding from the intramolecular interactions of cellulose to create soluble cellulose derivatives (Silva et al., 2008). Hydroxypropyl methylcellulose resembles a polymeric backbone that consists of a polysaccharide chain (Maki et al., 1999). Recent research has indicated that HPMC has a cholesterol-lowering effect (Carr and Gallaher, 1996; Dressman et al., 1993; Gallaher et al., 1993; Maki et al., 1999; Maki et al., 2000; Reppas et al., 2009; Swidan et al., 1996). Like other soluble fibers, HPMC is believed to form a viscous gel which interferes with the cholesterol, bile acids, and glucose absorption in the intestinal wall (Carr and Gallaher, 1996; Maki et al., 2000). In contrast to other soluble fibers such as guar gum and β-glucan, HPMC is resistant to colonic fermentation in the intestine (Maki et al., 1999). This means that HPMC could not be broken down by colonic bacteria and it remains intact through the gastrointestinal tract without producing gases and volatile short-chain fatty acids. This process can explain why HPMC has a lower incidence of gastrointestinal side effects, such as bloating, abdominal cramping, and flatulence, when compared with other soluble fibers (Maki et al., 1999).

Recent research has focused on METHOCEL (The Dow Chemical Company, Midland, MI), a commercial product of HPMC, as a cholesterol-lowering product that can be added to foods. Dressman et al. (1993) conducted a study where 10 g of METHOCEL (K8515) were added three times a day to the diet of normal and mildly hyperlipidemic humans. The results indicated that K8515 had the potential of clinical treatment for patients with mildly elevated cholesterol level. In another study about the cholesterol-lowering effects of HPMC in mildly hypercholesterolemic humans, Reppas et al. (2009) concluded that HPMC, especially high-viscosity grades, had a potential use as a treatment of hypercholesterolemia. In another high-molecular-weight HPMC study conducted by Maki et al. (2000), male volunteers with mild-to-moderate hypercholesterolemia consumed 5.0 g of HPMC from an orange drink per day, taken with or between meals for two weeks. The results indicated that HPMC had a significant and more consistent cholesterol reduction effects, as well as fewer gastrointestinal side effects when taken with meals in contrast to between meals. Maki et al. (1999) conducted a study to determine the doses of HPMC per day that could significantly reduce the total and LDL cholesterol in human subjects. Patients with mild-to-moderate hypercholesterolemia consumed 2.5, 5.0 or 7.5 g per day of HPMC for 6-week period. Significant reductions were found in both total and LDL cholesterol levels for 5.0 g and 7.5 g per day HPMC groups, but not for 2.5 g per day HPMC group, when compared with the placebo group. Compared with other soluble fibers, the minimum dose of HPMC needed to achieve cholesterol-lowering effects in the range of 5% to 10% is 5 g per day. Consumption within this range also had minimal gastrointestinal side effects

and is practical for daily consumption. In a study Swidan et al. (1996), cookie formulations and diet Jell-O® formulations which included HPMC (6.7 g of HPMC three times per day) had a greater than 15% reduction of LDL cholesterol level in relative to the placebo. It was concluded that the cookie formulation was used as a portable alternative to the diet Jell-O® formulation of HPMC. This study indicated that HPMC had the potential as a food additive to provide the cholesterol-lowering function in food. In a study of HPMC breads from Kim and Yokoyama (2010), hamsters were fed with high-fat diets supplemented with grain breads, including wheat, barley, barley with HPMC, debranned oat, and oat with HPMC. The results indicated that grain breads with HPMC significantly reduced the plasma LDL cholesterol level compared with control, and it was suggested that breads supplemented by HPMC be the potential staple food assisting in cholesterol control. Besides cholesterol-lowering effects, HPMC also has been widely studied for reducing postprandial blood glucose level and insulin excursion (Maki et al., 2008; Maki et al., 2007; Reppas et al., 1993; Reppas et al., 1999).

Hydroxypropyl methylcellulose has also been researched as a food ingredient to improve quality. In a study by Kim et al. (2011), 5% HPMC (w/w, flour basis) was added to whole wheat, oat, and barley breads. The results indicated that HPMC increased the loaf volume of the breads, and also decreased hardness by interfering with the interactions between proteins and starches, with no reduction in overall acceptability by sensory panelists, when compared with control bread.

Hydroxypropyl methylcellulose has also been added to meat products, since it can bind water by the formation of thermo-reversible gel upon heating and can also

retain the water when cooled. Hydroxypropyl methylcellulose can be soluble in cold water and the solubility decreases with increased temperature. The viscosity of HPMC solution is high in cold condition but decreases upon heating, until the viscosity is increasing rapidly when the gelation temperature reached (The Dow Chemical Company, 2002). The gel is thermo-reversible, primarily formed by the hydrophobic interaction between molecules containing methoxyl group, and it can return to the original HPMC solution state when cooled to cold condition (Silva et al., 2008). It means that the HPMC from gel can be soluble in the cold condition again to form a high viscosity solution, which has a high ability to bind water to reduce the loss of water when cooling. The addition of HPMC can lead to softer texture in the meat product, because HPMC could interfere the binding among meat proteins by the HPMC chains. In a study conducted byHill and Prusa (1988), methylcellulose (MC, 0.5 or 1.0%), or HPMC (0.5 or 1.0%) were added to lean ground beef patties. The results indicated that MC or HPMC did not significantly influence the moisture, fat, and protein content, but patties with HPMC received higher sensory scores on tenderness, juiciness, and off-flavor compared with those with MC or control. Chen and Huang (2008) developed a HPMC enhanced surimi products, and the addition of HPMC improved flow and handling properties of surimi and provided a soft gelatinous texture.

Hydroxypropyl methylcellulose can also be added as part of a pre-dust or batter of fried food. During frying or par-frying, oil can migrate into the coating and moisture can be lost from the meat block. The HPMC in the pre-dust or batter of nuggets to create a barrier to oil absorption and moisture loss (Pearson and Gillett, 1996). In one study by

Jamshidi and Shabanpour (2013), HPMC was added to the pre-dust (2%), batter (2%), or both pre-dust (1%) and batter (1%) of Talang queen fish nuggets. Compared with the control without HPMC, HPMC-coated nuggets significantly reduced oil absorption and moisture loss, and the nuggets containing 2% HPMC in the batter had the highest moisture retention and the lowest lipid content. Meanwhile, the use of HPMC in the coated fish nuggets had no negative effect on shelf life. In another fish nugget study by Chen et al. (2008), it was concluded that the thermal barrier for water diffusion formed by HPMC could significantly increase the crispness of HPMC-coated mackerel nuggets when compared with the control. For the studies on HPMC-coated Chicken nuggets, Pangborn (1978) and Sahin et al. (2005) reported that HPMC-coating nuggets reduced oil absorption and provided improved consistency to the batter.

Isomalto-oligosaccharide (IMO)

Isomaltose is a disaccharide linked by α-1, 6 linkages, while maltose is linked with α-1, 4 linkages. Oligosaccharides are carbohydrate polymers that contain three to ten monosaccharides units. Isomalto-oligosaccharides are branched oligosaccharides with glucose units connected by α-1, 6 linkages which are resistant to the digestion by human enzymes (FDA, 2005). The main compounds of IMO include isomaltose, isomaltotriose, panose, nigerose, kojibiose, and isomaltoteteraose. It can be produced from the enzymatic transformation of wheat, corn, rice potato starch and other starch sources (Goffin et al., 2011).

Isomalto-oligosaccharide is a low molecule weight soluble fiber, which is highly soluble in water and can be used as a low caloric sweeter. The caloric value is 1.5 kcal/g

which is much less than 3.9 kcal/g for dietary carbohydrates (Roberfroid, 1999). As a sweetener, IMO has anti-cariogenic activity. In a dental caries development study by Tsunehiro et al. (1997), it was found that the addition of a hydrogenated derivative IMO mixture to a sucrose-containing diet resulted in the reduction of caries development in rats infected with *S. sobrinus* 6715. *S. sobrinus* is highly related with the formation of caries within human teeth.

The most important function of IMO is its role as a prebiotic. Some research has focused on its bifidogenic properties. A study by Kohmoto et al. (1991) was conducted to determine the minimum effective dosage of IMO. The results indicated that the minimum of 10 g per day given to 9 adults for a 14-d period could significantly increase the numbers of fecal *Bifidobacterium*. Kohmoto et al. (1988) found that IMO could increase the numbers of bifidobacteria in the human feces which is an important prebiotic in the human intestinal system, but no significant changes for *Clostridium perfringens* and *Escherichia coli* which are unfavorable for human health and nutrition. It was concluded that bifidobacteria could utilize IMO but not for *Escherichia coli* and the other bacteria. Another study of determining the effects of IMO on rat intestinal microflora, Kaneko et al. (1990) noted that IMO could stimulate the growth of *Bifidobacterium* and suppress *Clostridium* growth in the animal study. In a study about both human and animal intestine by Gu et al. (2003), the analysis of fecal samples showed that IMO increased the growth of *Bifidobacterium* and *Lactobacilli*, but inhibited *Clostridium perfringens*. In a human study by Kaneko (1993), significant increases were observed in levels of *Bifidobacterium, Lactobacilli* and *Eubacteria* after

IMO intake. In addition, IMO can increase the fecal bacterial mass in diarrhea patients (Chen et al., 2001). Moreover, Rycroft et al. (2001) compared the fermentation properties of different probiotic oligosaccharides in *vitro*. It was concluded that IMO was effective at increasing the numbers of *Bifidobacterium* and *Lactobacilli* and it also resulted in the less generation of gas and bloating.

As a soluble fiber, some research has indicated that IMO has the function of maintaining healthy blood glucose and cholesterol level in the human body. As a low calorie sweetener, IMO is resistant to the digestion in human intestine, indicating that it has the potential to replace glucose for medical treatment such as diabetes. Sheng (2006) determined the glycemic index of IMO and xylitol in healthy adults. The results indicated that IMO had a lower glycemic index (34.66) compared with glucose. The glycemic index measures the rising level of blood glucose by consumption of foods, and the value of 100 represents pure glucose. In addition, IMO is a soluble fiber which is believed to be able to reduce postprandial blood glucose by slower gastric emptying, slowing glucose absorption and enhancing insulin sensitivity (Hesta et al., 2001). Hesta et al. (2001) fed dogs with a low-fiber control diet, a high-fiber diet, and control diet with 10% IMO for two d. The results suggested that the substitute of IMO had a beneficial effect on post-prandial hyperglycaemia. For the cholesterol-lowering effect of IMO, a study by Wang et al. (2001) indicated that there was a significant reduction in total cholesterol level and an increment in HDL level in hemodialysis patients that received 30 g of IMO daily for a 4-week period when compared with the control.

Moreover, IMO can be used to relieve constipation and regulate bowel movements (Wang et al., 2001). In a study by Chen et al. (2001), elderly people received 10 g of IMO daily for a 30-d period. The results indicated that the incorporation of IMO significantly increased the defecation frequency and stool output. Other studies also indicated that IMO had the ability to increase the absorption and retention of minerals such as calcium, magnesium, phosphorus, and iron (Kashimura et al., 1996; Ohta et al., 1993). Although IMO has many physiological benefits, the dosage needs be controlled on a patient-to-patient basis to prevent the negative side effects which include excess flatus, boating, and abdominal pains (Bouhnik et al., 2004).

In addition to nutritional qualities, IMO can also add functionality to a food product. For example, IMO can replace liquid sugar syrups with new functionalities to food products. Isomalto-oligosaccharides can also be used as a sweetener in food, such as being added to beer as a non-fermentable sugar syrup to regulate sweetness (Goffin et al., 2011). Isomalto-oligosaccharides can also be used as a humectant to maintain the moisture of food (Takaku, 1988). For example, the addition of IMO to sponge cake can help maintain texture and retard retrogradation. Limited studies have focused on the IMO application in meat products. It is believed that IMO can be added as a prebiotic to meat products to control the growth of pathogens and can provide health benefits as a fiber (Sendra Nadal et al., 2008)

Chicken nugget preparation

Chicken nuggets are a type of battered and breaded poultry product, which appeared in the American fast food restaurant market in the 1970s (Barbut, 2001). Initially, the chicken nugget was made from a whole chicken breast strip coated with a batter and breading and then fully cooked by frying. Currently, most chicken nuggets are made from small meat chunks of a single or a combination of different chicken meats. This includes white meat, dark meat, and sometimes chicken skin. Nuggets can also be manufactured in different shapes such as dinosaurs to appeal for the marketing of children. The standard procedures for manufacturing chicken nuggets include, mixing the meat and added ingredients, cooling the mixture, forming, coating (pre-dust, batter and breading), and cooking (fully-frying or par-frying then oven baking).

The first step is to grind the desired meat types to increase the surface area of the proteins for improved functionality. Muscle is covered by epimysium, which can protect the myofibrillar proteins from the extraction by salt solution. Grinding can break the epimysium of muscle to increase the efficiency of protein extraction (Owens et al., 2010). The next step is to mix the ground meat with a brine solution made from salt and phosphate blend which will absorb into the meat structure to assist with the extraction of salt-soluble proteins from muscle. Mixing provides the uniformity for different sources of meat and non-meat ingredients. If mixing is insufficient, meat proteins are not sufficiently extracted to increase the functionality such as WHC, and the ingredients will not be dispersed homogeneously. Being careful to not overly mix is important, because this will cause the meat proteins to be emulsified to create a gel texture and more

proteins will be denatured by heat caused by the friction which causes the loss of functionality. Generally, ice water is used to keep the meat cold and prevent the heat denaturation of proteins due to the friction of mixing.

Following mixing to uniformity, the meat batter is cooled to about -3.3 to -2.2C to not only reduce the temperature of the meat but also help with the forming of final nugget shape (Owens et al., 2010). If the temperature is above -2.2C, the meat will be viscid and too soft for forming which can result in shape deformities and the loss of product yield. If the temperature is too low, the formed meat can crumble and break into smaller pieces. Suitable meat temperatures can be achieved by adding dry ices, typically in the form of CO_2 snow, to the mixer. Following mixing and cooling, the CO_2 snow must be allowed to dissipate from the meat surface to prevent the defects, such as deformed shape and splashing of oil during frying, due to the evaporation of CO_2 by heating.

Following mixing and cooling of the meat, the meat batter is added to the former and pressed into different templates to form a desired shape that generally includes orbicular, elliptical, and semilunar, but can also be formed into popular shapes, such as dinosaur, star, and cartoon characters.

Coating

Coating, which includes adding a pre dust, batter, and breading to the formed meat block, creates texture, flavor, and appearance which are desirable to consumers. Value-added breaded products have a higher economic value with increased yield to processors and lower costs to consumers. After the forming step, pre-dust, batter, and

breading are added to crust-frozen nuggets successively. Pickup represents the increased amount of weight during battering and breading process based on the raw weight. Due to labeling standards in the USA, coating pickup is to be labelled as a breaded product and must not exceed more than 30%, otherwise it must be labeled as a fritter (USDA, 2015).

Pre-dust

Pre-dust is a protein-base coating used to increase the adhesion ability of the batter and breading. Pre-dust is only applied when the surface of meat has low adhesion ability. For example, whole meat muscle, such as tenders, has low adhesion ability because of the hydrophobic surface of meat membrane. The pre-dust will adhere to the meat surface by absorbing the free water from meat, creating an intermediate layer between the meat and batter (Barbut, 2001). The major components of a pre-dust are flours, cracker meal, and some seasonings and spices to increase functional flavors. Non-meat proteins, such as soy, egg albumen, and whey, will be added to the pre-dust to increase the adhesion ability.

Batter

Batter is a liquid suspension of dry ingredients, which is applied to coat the product and increase the adhesion of breading. The components of batter include wheat flour, corn flour, proteins (wheat, egg, dairy and soy), seasonings, gum, coloring, and occasionally leavening agents for tempura-type battered products. Proteins are used to assist the adhesion and texture-binding while gums can increase the viscosity to promote the suspension of solid ingredients (Barbut, 2001). The viscosity of batter is important for pickup and yield of the products, and is determined by a viscosity cup such as the

Zahn or Stein cup. These devices measure the viscosity by observing the draining time of the batter. Batters can be classified as adhesion, cohesion, or tempura batter (Barbut, 2001). Tempura batters, which do not require the addition of breading, are typically made with wheat and rice flour base. The tempura batters will puff during frying process to create the crispy texture by capturing air since the frying process causes the evaporation of gases produced by the leavening agents (Owens et al., 2010). Adhesion batters usually have a lower viscosity and form a thin coat which sticks to the meat surface. For adhesion batters, the common dilution of dry ingredients to water volume is from 1:1.4 to 1:1.9 (Barbut, 2001). Cohesion batters, which are normally thicker than adhesion batters, are used to form a shell around the product.

Breading

Breading is the outer layer of chicken nuggets that improves the appearance and provides the texture, as well as increasing in yield. Breadings are usually comprised of cereals that are baked and ground into flour in either medium or large crumbs (Barbut, 2001). Generally, large–sized breadings have a higher pickup due to the coarse texture but have an unequal and irregular coverage of product surface. Small-sized breadings have a lower breading pickup but a more uniform appearance. From small to large size crumbs, four types of breadings are usually used in meat products: flour, cracker meal, home-style or American bread crumbs, and Japanese bread crumbs (Owens et al., 2010).

Cooking

Breaded chicken nuggets can be either fully fried or par-fried followed by oven baking for final cooking step. Par-frying, 20-30 sec dip in 195-200C oil, starts to set

coating, change color, and produce flavors, which are preferable to consumers. The coating is set by the interaction between the myofibrillar proteins from the meat block and the proteins in the batter through the heat denaturation (Owens et al., 2010). The golden color is from the Maillard reaction between amino acids and reducing sugars in the batter and breading from the heat process. The desirable flavor compounds are mainly from the oxidation of linolenic or linoleic acid, such as dienal, alkenals, lactones, hydrocarbons, and various cyclic compounds (Choe and Min, 2007). After par-frying, the products can either be deep fried or oven baked for the final cook step. Oven baking, which is the most common in the food industry, requires the internal temperature of chicken nuggets to reach 73.9C (165F) for food safety practices.

Deep frying as a final cook step is also important to help develop the brown or gold color of chicken nugget surfaces and assists the coating adhered to the products (Barbut, 2001). Frying is less common in production practices due to the risk of oil fire, oil disposal issues, as well as the higher management practices required for oil frying. In addition, nutritionally speaking, fully fried products have higher oil content compared with par-fried products. For example, Saguy and Dana (2003) reported that the French fries by fully frying (14.8%) had a much higher oil content compared with the ones by par-frying (7.6%). In addition, fully frying can lead to non-uniform shapes and more product defects when compared with oven cooking, such as broken holes due to excessive puff by the evaporation of moisture.

Meat qualitative analysis

The water in meat is classified as bound water, immobilized water, or free water. Bound water is attracted by meat proteins; immobilized water is held by steric effect or attracted by bound water; free water is held by weak surface forces and can be easily squeezed out of the meat (Barbut, 2001). These classifications can be tested through WHC which is described as the ability of meat proteins to retain water. The myofibrillar proteins (~50-56% of meat proteins) are the major proteins responsible for binding and holding water during meat processing. Myosin and actin can be solubilized in a salt solution to expand the steric structures by ionic strength allowing the proteins to create more available sites to bind water. This increases the ability of holding bound and immobilized water, affecting WHC, color and texture.

Yield parameters

Generally, pickup, par-fry yield, cook loss, freeze loss, and final yield are used to represent the yield parameters of chicken nuggets. Final yield (%) determines the percentage of the increased weight of final product weight based on the uncoated weight. Pickup (%) measures the increased percent of coating weight from the battering and breading process based on the raw weight. Pickup is highly affected by the adhesion ability of batter and the granule size of breading. Normally, higher viscosity of batter and larger size of breading result in a higher pickup. Kim et al. (2010) found that mushroom powders with a larger granule size, had a higher pickup for uncoated carrots compared with the small size. Pre-dusting can also increase pickup by approximately 6.0 % when using pre-dust equipment (Barbut, 2001).

Par-fry yield (%) represents the percent of the increased weight based on the initial weight during the fry process. Oil temperature and frying time need be controlled during the frying. A higher frying temperature results in less frying time and lower oil uptake but lower yield for final cooking compared with lower frying temperature. Yang and Chen (1979) looked at these factors and reported that the yield and cooking time of different poultry parts reduced with the increased frying temperature (163C, 174C and 185C). (Dana and Saguy, 2006); Kita et al. (2007) also concluded that the potato crisps fried by different oils at a low temperature (150C) had a higher fat content compared with those from high temperature (190C). Two mechanisms have been described the oil uptake. First, evaporated water can be replaced by oil during frying; second, when cooling, the oil in the food surface is continuously absorbed by the pressure gradient created by the moisture evaporation (Dana and Saguy, 2006). This moisture loss could be reduced by the addition of water-holding compounds to the coating to create a water barrier. In the study by Jamshidi and Shabanpour (2013), 2% HPMC in the batter had the highest moisture retention in fish nuggets.

Cook loss (%) is the percent of weight loss based on the pre-cooked weight during the final cooking step. Higher internal temperature of final product and higher oven temperature, can lead to a higher cook loss due to the higher evaporation of moisture. Oven baking is generally comprised of an air convection oven with moisture control that has been applied to achieve the effective heat transfer without the increased cooking time and to improve moisture retention. Increasing the humidity can increase heat transfer coefficient, reduce cook time, and prevent moisture migration in meat

product (Murphy et al., 2001). Ngadi et al. (2006) reported that the moisture loss of the core portion of chicken nuggets changed little in the early stage of frying or oven baking but then increased as cooking continued. This was because the coating reduced the moisture loss in the core portion of chicken nuggets. Moisture was rapidly lost in the breading portion within the first few minutes of deep frying or the first 15 min of oven baking, and then was reduced at the consistent rate. Less moisture loss can be achieved by par-frying followed by oven baking, compared with the method of a full deep fry. As describes with par-frying, the reduction of cook loss can be achieved by creating a water barrier in the coating step. This can be seen in a study by Jamshidi and Shabanpour (2013), where the HPMC that was added to the pre-dust or batter would form a water barrier to reduce the moisture loss.

Freeze loss (%) measures the percent of weight loss during the freezing storage based on the cook weight. Freezing is applied to keep the appearance and freshness of a food allowing for a longer shelf life to allow for distribution and storage. The freezing temperature and surface area can affect the weight loss of food; generally there is an increased weight loss with a higher temperature and a larger surface area. The major weight loss contributor is moisture loss, which is caused by the evaporation of water from the product surface before it is frozen along with the sublimation of ice from the product during the freezing storage (Rao and Novak, 1977). This freeze loss can be reduced by increasing the WHC of food product by adding HPMC which can bind water under cold condition.

Color

Color is essential for consumer acceptability and preference of food products. The color of an object which the human eyes observe is due to the reflected light from that object. Human eyes can detect the hue differences by specific descriptive terms such as red, blue, yellow and green while simultaneously being able to describe the Chroma difference by intensity and the value differentiated by brightness. Due to the limitation of visual description, reflectance colorimetry is the most common way to detect poultry meat color. Minolta and Hunter LAB colorimeters are the most common used in the meat industry. To descript the color in quantified numbers, CIE (Commission International de l'Eclarirage) developed CIE X, Y, Z system to define the color by three primary colors, X (red), Y (green) and Z (blue) in the 1930s (Barbut, 2001). Then it was replaced by CIE L*a*b* (CIELAB) color space system in the 1970s because the value differences are not easily detected by human eyes. L*, a* and b* values are used to determine the color characteristic in the CIELAB system. L* value represents the lightness of surface ranging from 0 (black) to 100 (white); a* value measures the amount of red or green, with positive value indicating red and negative value indicating green; b* value represents yellow or blue, with positive value indicating yellow and negative value indicating blue (Minolta, 1998). The lightness of a meat product is influenced by the denaturation of meat proteins and extracellular water. For raw meat, the denaturation of proteins results in lower WHC with more extracellular water on the surface, which can increase the scattering of light and increase the lightness.

For chicken nuggets, the color of breading is golden (par-frying) or brown (fully frying), resulting from the Maillard reaction. This breading color can be affected by one or more factors including but not limited to breading materials, frying oil, frying time, and frying temperature. The color of the core region appears as a gray cooked color, because the protein part of meat pigment (myoglobin) is denatured by the heating. Color can also be influenced by meat composition and final cook temperature. Prinyawiwatkul et al. (1997) incorporated flours processed from fermented cowpeas and fermented partially defatted peanuts into the core portion of chicken nugget, which resulted in higher a*, and lower L*and b* value in the meat block compared with control.

Texture

Texture is another important characteristic of food products used to meet consumer satisfaction. Texture of meat products are developed by the interaction of functional ingredients and meat proteins, especially the denaturation of meat proteins for cooked products. Texture includes many textural attributes, such as tenderness, hardness, crispness, and mouth-feel. Several methods have been developed for textural parameters, including shear, penetration, compression, tension, and torsion (Barbut, 2001). Textured profile analyses use compression tests to evaluate hardness, springiness, cohesiveness, fracturability, and adhesiveness (Rosenthal, 2010).

Shear test is a common test to determine the tenderness of meat product. There are two kinds of shear force tests that are more commonly used in further processed poultry products, Warner Bratzler (WB) and Allo-Kramer (AK). The WB device uses a single blade to cut the meat sample and record the peak force required to shear the

sample. The AK device uses a cell consisting of 10 to 13 blades in a square box to shear the sample and records the peak force (Barbut, 2001). More recently, the Meullenet-Owens Razor shear device is used to predict the tenderness of poultry cooked meat, using a razor blade to cut cross sample (Meullenet et al., 2004). For chicken nuggets, the core portion is usually pre-cut into the standard size for shear force evaluation. A higher fat content in chicken nuggets leads to a more tender texture because fat interferes with the interactions between meat-binding proteins (myosin and actin) which can act as emulsifiers to bind fat. Incorporating fiber can also reduce the interaction between meat particles, resulting in a tender texture. In the study by Prinyawiwatkul et al. (1997), the shear force measured by WB was found significantly lower in the chicken nuggets incorporated with dietary fiber products compared with the control.

Determination of fiber contents

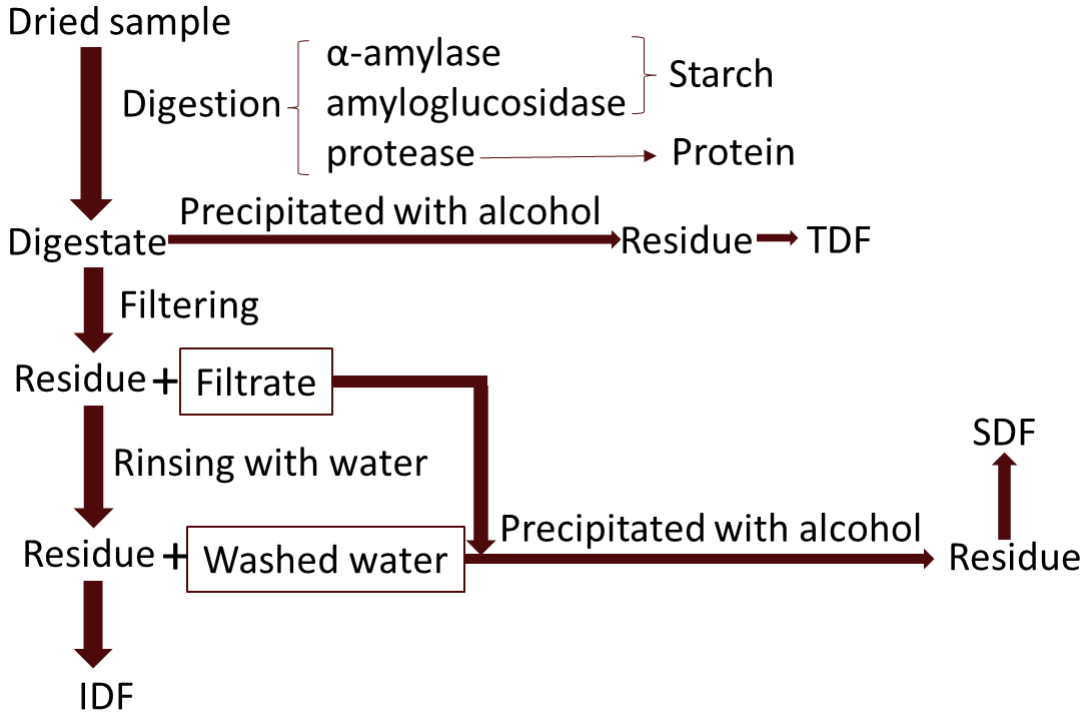
Many methods have been developed to measure the content of total dietary fiber (TDF), soluble dietary fiber (SDF), and insoluble dietary fiber (IDF) in different matrices. The main categories of dietary fiber analysis are gravimetric methods, enzymatic methods, enzymatic-gravimetric methods, enzymatic-chemical methods, and enzymatic-gravimetric-liquid chromatography methods (Champ et al., 2003). The gravimetric methods were adapted to be able to measure the cellulose, lignin, and hemicellulose, which are not traditionally measured in a food analysis (Van Soest and Wine, 1967). Enzymatic-gravimetric methods and enzymatic-gravimetric-liquid chromatography methods are widely applied for measuring dietary fiber contents in the food system.

The enzymatic-gravimetric method, Association of Official Analytical Chemists (AOAC) Official Methods 985.29 and 991.43, is the most common method used in food (AOAC International, 2005a,b). Before testing, food samples are dried and the fat is extracted if containing more than 10% fat. From Figure 1, dried samples are digested by heat-stable α-amylase first, hydrolyzing α-1, 4 linkages of carbohydrates to produce mainly maltose, maltotriose, and branched α-limit dextrins (Warren et al., 2015). Then the samples are sequentially digested by proteases to remove proteins and are digested by amyloglucosidase to convert the products from α-amylase digestion to glucose. For TDF, the residue from the digestion is washed with alcohol and acetone, dried, and weighed; for IDF, the digestate is filtered, and the IDF residue is washed with water, then dried, and weighed; for SDF, the filtrate and washed water from IDF residue are combined to precipitate again with alcohol, filtered, dried, and finally weighed (AOAC International, 2005b) All three values are corrected for protein, ash, and blank.

Enzymatic-gravimetric-liquid chromatography method AOAC Official Methods 2009.01 and 2011.25 have been developed to overcome the disadvantages of the previous method (AOAC International, 2012a,b). In principle, these new methods are based on the previous methods. From Figure 2, dried and defatted sample is sequentially digested with α-amylase, amyloglucosidase, and protease to remove starch and protein, then IDF is determined by the residue from the filtrating of digestate. Soluble dietary fiber precipitate (SDFP), which is water soluble but water: alcohol insoluble, is precipitated by ethanol from the filtrate of IDF. Nonprecipitable water:alcohol soluble dietary fiber (SDFS) is recovered and concentrated from the filtrate of SDFP. The

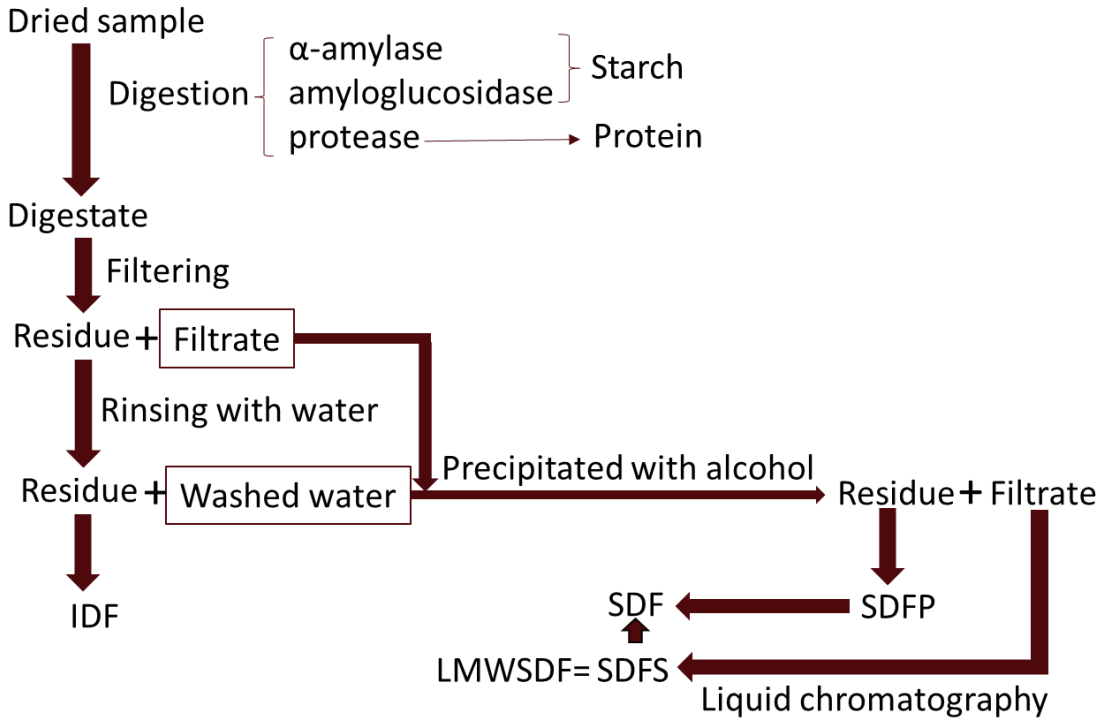
content of SDFS is measured by liquid chromatography. SDFS represents low molecular weight soluble dietary fiber (LMWSDF). All the values are corrected by protein, ash, and blank. This means that SDF is the sum of LMWSDF (SDFS) and SDFP, and TDF is the sum of IDF, LMWSDF (SDFS) and SDFP.

Figure 1. Basic Procedures of AOAC Official Methods 985.29 and 991.43



AOAC: Association of Official Analytical Chemists
TDF: Total dietary fiber
SDF: Soluble dietary fiber
IDF: Insoluble dietary fiber

Figure 2. Basic Procedures of AOAC Official Methods 2009.01 and 2011.25



AOAC: Association of Official Analytical Chemists
SDF: Soluble dietary fiber
IDF: Insoluble dietary fiber
SDFP: Soluble dietary fiber precipitate
SDFS: Nonprecipitable Water: Alcohol Soluble Dietary Fiber
LMWSDF: Low molecule weight soluble dietary fiber

High molecular weight dietary fiber (HMWDF) can be measured as the sum of IDF and SDFP from AOAC Official Methods 2009.01 and 2011.25. It can be divided as insoluble and soluble HMWDF. The insoluble includes cellulose, lignin and insoluble pectin; the soluble include gums, β-glucan and HPMC. Low molecular weight soluble dietary fiber represents indigestible but highly water-soluble and low-molecule-weight carbohydrates, like fructose oligosaccharides, galactose oligosaccharides, IMO, xyloligosaccharides, resistant maltodextrins, insulin, and polydextroses. The TDF is also

the sum of HMWDF and LMWSDF. Resistant starch (RS) is defined as the fraction of dietary starch, which escapes the digestion in the small intestine of human (Sajilata et al., 2006). Resistant starch contains RS_1, RS_2, RS_3 and RS_4. Resistant $starch_1$ is the resistant starch in the physically inaccessible form; RS_2 represents the resistant starch that is in a certain granular form; RS_3 represents the retrograded starch that forms during the cooling and cooking of gelatinized starch; RS_4 represents the chemically modified starch by chemical treatment with new chemical bonds formed.

For Enzymatic-gravimetric methods, AOAC Official Methods 985.29 and 991.43 cannot measure LMWSDF including IMO that does not precipitate in 78% aqueous ethanol, but can determine SDFP and IDF content. Also some resistant starches from categories RS_1, RS_2 and RS_4 are not included in the result, either. However, AOAC Official Methods 2009.01and 2011.25 can measure the dietary soluble fibers that do not precipitate in 78% aqueous ethanol with the degree of polymerization being 3 or higher. These soluble fibers are LMWSDF, and most RS are also incorporated in the result, except some RS_4 depending on type (Zielinski et al., 2013). McCleary (2014) modified AOAC Official Methods 2009.01 and 2011.25 to remove resistant maltodextrins which could from by the hydrolysis of starches by pancreatic α-amylase and amyloglucosidase during the testing. The removal was achieved by the additional incubation of SDFS by amyloglucosidase at 60C.

Hydroxypropyl methylcellulose is a high molecular weight soluble fiber that forms MC gums in food products. Hydroxypropyl methylcellulose can be dissolved in cold water, but the solubility of HPMC decreases as temperature increases. The viscosity

of HPMC solution also decreases with increasing temperature until it forms a gel by heating (The Dow Chemical Company, 2002). In addition, HPMC is a thickening agent that may cause the filtering issues during the analysis of fiber contents by the former two methods. To overcome this disadvantage, AOAC Official Method 2006.08 was developed to measure MC and HPMC food gums in food system. Basically, after the digestion of removing starch and protein, sample is chilled to fully hydrate the methylcellulose food gums (MFG), and then the residue after filtering is analyzed by liquid chromatography with the refractive index detection (AOAC International, 2007).

Isomalto-oligosaccharides are a type of fiber with a low molecular weight which is highly water-soluble in foods. Hayakawa et al. (2000) developed a high performance liquid chromatographic (HPLC) method to determine seven saccharides in sake. The results showed that IMO compounds, iosmaltose, isomaltotriose, and panose, were observed with unidentified peaks. The high performance liquid chromatographic (HPLC) method with a polymer-based amino column for determining the IMO content in commercial IMO products was improved by Nakanishi et al. (2006). The results indicated the higher amount of IMO was detected by the improved method compared with the conventional method and an unknown component was identified as isomaltotriosylglucose.

CHAPTER II

EVALUATION OF SOY CHICKEN NUGGETS

Introduction

Chicken nuggets are a common choice for consumers in fast food restaurants, especially for children. The breading of chicken nuggets gives new flavors and texture besides chicken meat. As a type of fried foods, frying process creates desirable flavor compounds and golden color for breaded products but increases the fat and caloric content of food (Fillion and Henry, 1998). As junk food, the consumption of fried foods could increase the risk of obesity, diabetes, cardiovascular diseases, and cancer (Stender et al., 2007).

Fibers are indigestible carbohydrates which can provide health benefits in humans by reducing the risk of developing cardiovascular diseases (Lairon et al., 2005; Liu et al., 1999), diabetes (Montonen et al., 2003), obesity (Van Itallie, 1978), and certain gastrointestinal diseases (Petruzziello et al., 2006). Moreover, fibers especially soluble fibers have the functions of reducing serum cholesterol and blood glucose level (Anderson et al., 2009). Unfortunately one serving size (60-90 g) of commercial chicken nuggets (e.g. McDonald™ McNuggets™ and Tyson Chicken Nuggets) contains only 1 g of dietary fiber (McDonald's Corporation, 2014; Tyson Foods Incorporation, 2014).

Functional fibers are isolated and indigestible carbohydrates that have beneficial physiological effects in humans (Institute of Medicine, 2004). Two types of commercial functional fiber products have been used in this study, hydroxypropyl methylcellulose

(HPMC) and isomalto-oligosaccharide (IMO). Both fibers are soluble fibers that have cholesterol-lowering effects. The mechanism of cholesterol reduction in humans by these fibers are not fully established, but it is mostly accepted that soluble fibers may form a viscous matrix in the small intestine, interfering with bile acid and cholesterol absorption (Eastwood and Morris, 1992; Theuwissen and Mensink, 2008)

Hydroxypropyl methylcellulose is a semisynthetic cellulose derivative with the substitutions of methyl and hydroxylpropyl groups for hydroxyl groups of a cellulose. Recent research has indicated its function of reducing serum cholesterol level, and low incidence of gastrointestinal side effects due to the resistance to colonic fermentation in human intestines (Carr and Gallaher, 1996; Dressman et al., 1993; Gallaher et al., 1993; Maki et al., 1999; Maki et al., 2000; Reppas et al., 2009; Swidan et al., 1996). Some studies added HPMC to the coating (pre-dust or batter) of meat nuggets, and the results indicated that it could create a barrier to prevent the loss of moisture and reduce the oil absorption (Chen et al., 2008; Jamshidi and Shabanpour, 2013; Pangborn, 1978; Sahin et al., 2005). In addition, HPMC has been used in other meat products such as sausage and meat patty because of its water holding capacity (WHC) and gel texture (Chen and Huang, 2008; Hill and Prusa, 1988) It can be soluble in cold water but the solubility decreases with increased temperature, and it will begin to form thermo-reversible gel when gelation temperature reaches, but the gel will reserve to solution when cooled (The Dow Chemical Company, 2002)..

Isomalto-oligosaccharides are branched oligosaccharides with glucose units connected by α-(1, 6) linkages which are digestion-resistant for humans. Research

indicates that IMO has the functions as a low caloric sweetener (Roberfroid, 1999), as a prebiotic (Chen et al., 2001; Gu et al., 2003; Kaneko et al., 1990; Kaneko, 1993; Kohmoto et al., 1988; Kohmoto et al., 1991; Rycroft et al., 2001), and able to reduce blood glucose (Hesta et al., 2001; Sheng, 2006) and cholesterol levels (Wang et al., 2001) and to relieve constipation (Chen et al., 2001).

Some earlier research by others have reported that commercial dietary fiber products, such as flours processed from fermented cowpeas and fermented partially defatted peanuts (Prinyawiwatkul et al., 1997), roasted pea flour (Singh et al., 2008), pea hull flour, gram hull flour, bottle gourd and apple pulp (Verma et al., 2009; Verma et al., 2010), can be added as extenders to the meat block of chicken nuggets to increase the dietary fiber content while retaining acceptable sensory properties. However, none of these earlier studies used commercial functional fiber products with high purity of specific types of soluble fibers such as HPMC and IMO, which could provide more health benefits. Also the dietary fiber content of most these fiber-incorporated chicken nuggets were not higher than 2.5 g per serving, which does not meet the criteria to be labelled as a "Good Source" of fiber (FDA, 2015).

Due to the low fiber intake of consumers in the USA and the low fiber content of chicken nuggets, two specific types of functional fibers, HPMC and IMO, have been incorporated in the meat block of soy chicken nuggets in this study. The objective was to increase the total dietary fiber (TDF) content of soy chicken nuggets by more than 2.5 g of fiber per serving, which could be claimed as "Good Source" of fiber. Fiber-added soy

chicken nuggets were produced to evaluate the effects on yield, color, texture and fiber content compared with control soy chicken nuggets.

Materials and Methods

Soy chicken nuggets preparation

Chicken nugget samples were prepared at the Poultry Science Research, Teaching and Extension Center, Texas A&M University, College Station. Fresh boneless skinless chicken breast meat was purchased from a local meat distributor (< 1 week postmortem). The breast meat was trimmed to remove fat prior to grinding (Model TCA12, Butcher Boy, Birmingham, OH) through a 3/8'' plate 1 d prior to preparation of the chicken nuggets. Meat was stored in plastic food grade tubes in a walk-in cooler at 4C.

Table 1. Chicken Nugget Meat Block Formulations Used for Manufacturing the Control and Fiber-added Soy Chicken Nuggets

Ingredients	Control	Treatment
Meat	60.91%	53.84%
Water	7.74%	7.03%
Salt	0.74%	0.74%
Phosphate	0.61%	0.61%
Hydrated TSPC[1]	30.00%	30.00%
IMO product[2]	0.00%	5.75%
HPMC product[3]	0.00%	2.03%
Total	100.00%	100.00%

[1] TSPC: Textured soy protein concentrate, hydrated with tap water on a water weight to TSPC weight ratio=3:1
[2] IMO: Isomalto-oligosaccharide, powdered
[3] HPMC: Hydroxypropyl methylcellulose, powdered

The control and treated nuggets' formulations for the meat block are presented in Table 1, and are similar to those used in industry for the same product type. Textured soy protein concentrate (TSPC) (Response® Soy protein 4410, Solae Limited Liability Company, St. Louis, MO) was first fully pre-hydrated with water at a ratio of 3:1 (tap water weight: dry TSPC weight). The hydrated TSPC was then added at 30% of the total meat block weight. A mixed brine composed of tap water, salt (Morton table salt, Morton Salt Inc., Chicago, IL) and phosphates (Blend 100, Francee Flavoring and Spice, Ankeny, IA), was added at 10% of the total weight of meat and hydrated TSPC, resulting in a concentration of 0.6% salt and 0.5% phosphates in the final product. For the treatment nugget, 3.0 g of fiber per serving were added as filler to ground breast meat. The blend of functional fibers was composed of 30% HPMC (METHOCEL K100M, food grade modified, The Dow Chemical Company, Midland, MI) and 70% IMO (VitaFiber^{TM}, BioNeutra North America Incorporation, Edmonton, Alberta, Canada). This blend was determined by preliminary experiments based on the sensory texture and flavor of chicken nuggets. Detailed information about the preliminary experiments can be found in Appendix A.

The ground breast meat and ingredients (total of 13.6 kg per batch) were mixed (BX35A Filling Mixer, Guangdong Henglian Food Machinery Co., China) for 1 min, then blended with dry ice pellets for 10 min until the temperature was chilled to -3.3 to -2.2C (Owens et al., 2010). Chilling to this temperature is a standard practice used on formed products. Following mixing, the cold meat batter was moved to a nugget former (No. B11651, Quality Food Equipment, Denver, Co). Blank nuggets, without batter and

breading, were formed using a standard chicken nugget shaped mold (Quality Food Equipment, Denver, Co). Forty nuggets to a pan were placed individually, with a space to avoid bonding prior to crust-freezing in a -28.9C blast freezer (Hobart, Model W, Troy, OH). After 30 min of crust freezing, the weight of the blank nuggets (raw weight) was recorded.

Before coating, batter ingredients (G70921, Kerry Ingredients & Flavours, Tralee, Iceland) were mixed with tap water to reach the manufacturer recommended viscosity of 16 sec as by a Zahn cup (Size No.2, VWR International, Houston, Texas). The blank nuggets were immersed in the batter and covered with breaders (G4106, Kerry Ingredients & Flavours, Tralee, Iceland) sequentially, using an Automatic Batter Breading Machine (Model ABB, Bettcher Industries, Inc., Vermilion, OH). After coating, the weight of coated nuggets for each group was recorded as coating weight.

The coated chicken nuggets were par-fried at 190C in Canola oil using a deep fryer (Star 301HLF Electric Countertop Commercial Deep Fryer, Star Manufacturing International, Inc., St. Louis, MO) for 30 sec to set the breading. The weight of each group after par-frying was also recorded as par-fry weight. Following par-frying, the samples was freezing in a -28.9C blast freezer (Hobart, Model W, Troy, OH). After 24 hr, the nuggets were baked in a convection oven (Blodgett/Zephaire, Model Zephaire-G-L, Burlington, VT) for 45 min until the internal temperature reached 74C (165F). When the samples were cooled to room temperature, the weight after fully cooking was recorded per batch as cooked weight. Next, cooked nuggets were placed in a -28.9C blast freezer (Hobart, Model W, Troy, OH) until frozen, and the weight was recorded

after 24 hr. The nuggets were then stored in the -12.2C freezer (Hobart, Model W, Troy, OH) until analysis. Raw weight, coated weight, par-fry weight, cooked weight, and frozen weight were recorded with 10 groups for each treatment and 15 nuggets per group.

Pickup (%), par-fry yield (%), cook loss (%), freeze loss (%), and final yield (%) were calculated as follows:

$$\text{Pickup}\% = \frac{\text{Coated weight} - \text{Raw weight}}{\text{Raw weight}} \times 100\%$$

$$\text{Parfry yield}\% = \frac{\text{parfry weight} - \text{Coated weight}}{\text{Coated weight}} \times 100\%$$

$$\text{Cook loss}\% = \frac{\text{Coated weight} - \text{Cooked weight}}{\text{Coated weight}} \times 100\%$$

$$\text{Freeze loss}\% = \frac{\text{Cooked weight} - \text{Frozen weight}}{\text{Cooked weight}} \times 100\%$$

$$\text{Final yield}\% = \frac{\text{Frozen weight} - \text{Raw weight}}{\text{Raw weight}} \times 100\%$$

Color evaluation

Color (L*, a* and b* value) of control and treatment soy chicken nuggets were analyzed using a Minolta colorimeter (Model CR300, Konica Minolta Business Solutions U.S.A. Inc., Ramsey, NJ) calibrated with a channel 00 plate. After 48 hr processing, two replications of 25 frozen soy chicken nuggets from each treatment were reheated to 74C by a convection oven (Blodgett/Zephaire, Model Zephaire-G-L, Burlington, VT). After cooling to room temperature, samples were cross cut horizontally and meat color was measured with an illuminant C source, an aperture size of 8 mm and an observation angle of 0^0, and as an average of triplicate readings per nugget.

Shear force

Texture was measured by slice shear force (SSF) using a 50 kg load cell with a cross head speed of 500 mm/min on a Universal Testing System Machine (United 5STM-500, Huntington Beach, CA). When 48 hr after processing, two replications of 25 frozen soy chicken nuggets each from control and treatment groups were reheated to 74C using a convection oven (Blodgett/Zephaire, Model Zephaire-G-L, Burlington, VT). The samples were cooled to 4C, prior to cutting the meat block into a cube (1.0 cm L*1.9 cm W*1.9 cm H). Peak force of the sample was recorded in kilogram-force (kgf), and then converted to Newton (N) by multiplying g-force (9.80665 N/kg).

Fiber content

Total dietary fiber (TDF), soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) content of soy chicken nuggets were measured by Covance Laboratories (Madison, WI). Five frozen nuggets were ground in a blender (Oster® 14 speed, Neosho, MO) after dipping into liquid nitrogen. The ground samples were stored in a Styrofoam cooler with dry ice and shipped overnight to Covance Laboratories. One composite of five ground nuggets from each treatment was tested for TDF, SDF and IDF by Association of Official Analytical Chemists (AOAC) Official Method 985.29 and 991.43. However, results were much lower than expected. Both samples were re-analyzed using AOAC Official Method 2009.01 and 2011.25. Although higher amount of fiber was detected by this new method, the results were still lower than expected. In order to clarify the correct fiber content and possibly help explain the low levels recorded in the previous sample, the HPMC and IMO powdered products used in the treated nuggets, and blank treatment

nuggets without breading were sent for TDF, SDF and IDF content using AOAC 2009.01 and 2011.25.

Statistical analysis

The data of yield parameters, color values, and shear force were analyzed by Analysis of Variance (ANOVA) (ProcGLM) of Statistical Analysis System (SAS) (version 9.3, SAS Institute Inc. Cary, NC) with a significance level of $P < 0.05$. Treatment, replicate, and the interaction between treatment and replicate were included as main effects. If the interaction was not significant ($P > 0.05$), interaction was removed from main effects. Means from each treatment were calculated and separated if a difference ($P < 0.05$) was determined.

Results and Discussion

Yield parameters

Yield parameters are quick indicators of quality and are therefore of importance to manufacturing companies and consumers. Any increase or loss in yield may indicate a low water retention capacity, adhesion, or other effects caused by the ingredients, and possibly produce a tougher product to the consumer or monetary loss to manufacturer. Pickup%, par-fry yield%, cook loss%, freeze loss%, and final yield% were calculated for both control and treated nuggets (Table 2). After statistical analysis no difference ($P > 0.05$) was observed in the interaction between treatment and replication for all five yield parameters. Data was re-analyzed and replications pooled for statistical analysis.

Pickup of batter and breading is essential for yield as well as both visual and flavor sensorial effects. Too viscous batters could create a feathering effect which causes

belt marks of products in automated production lines. In contrast, when batters have lower viscosities, void areas could occur. This issue causes inconsistencies in appearance and texture. Higher application pressures of breading materials may cause false adhesions that create voids during the par-frying step. In this experiment, pickup was controlled by adjusting the viscosity of the batter with a Zahn cup No. 2 and the pressure of the adhesion of breading during automated batter and breading process. There was no significant difference in pickup between the control (23.59%) and the treatment (23.04%). Pickup can be highly affected by the adhesion ability of batter and the size of the breader granules not the meat block; therefore the results were expected since the supplementation of fiber in the meat block is not a major factor influencing pickup results. Sahin et al. (2005) and Altunakar et al. (2006) added 1% HPMC in the batter flour mix for deep-fried chicken nuggets and the results indicated that HPMC significantly increased pickup compared with the control samples. Hydroxypropyl methylcellulose is a thickening agent that can increase the viscosity of batter, leading to the increase of pickup during the process (The Dow Chemical Company, 2002).

Table 2. Mean and Standard Deviation of Yield Parameters Measured on Control and Fiber-added Soy Chicken Nuggets.

Treatment[1]	Pickup%	Par-fry yield%	Cook loss%	Freeze loss%	Final yield%
Control	23.59±0.14	3.05±0.13	4.56±0.39	1.82±0.12	19.45±0.47
Treatment	23.04±0.32	2.65±0.10	4.27±0.37	1.46±0.07	19.16±0.72
P value	0.0583	0.0169	0.3264	0.0061	0.5551

[1] Means were calculated from 10 composite groups containing 15 nuggets, and group weights were collected from 2 replications (n=20); significant difference was found when $P < 0.05$.

During par-frying, the control nuggets had a significantly higher yield (3.05%) when compared with the treatment (2.65%) indicating that the treated nuggets gained less weight during the par-frying process. The cause of this significant difference could be due to the increased loss of moisture in the treated nuggets or the limited absorption of oil during the frying process. During the frying process moisture is lost in the form of steam. The steam is created by the rapid heat exchange between the water in the meat block and oil. As the steam vacates the nugget, an exchange of fluid occurs, particularly oil.

A small test of measuring moisture and fat content of soy chicken nuggets was conducted, with two samples from both control and treatment measured in duplicate. The thawed samples from frozen storage were ground by a blender (Oster® 14 speed, Neosho, Missouri). The moisture content was determined by initial microwave drying using a CEM SMART TRAC^{TM} System 5 moisture analyzer (CEM Corp, Mathew, NC), then the fat content of dried sample was read by Smart System 5 ProFat^{TM} Analyzer (CEM Corp, Mathew, NC) using nuclear magnetic resonance. The results showed that the moisture content of the treated nuggets (57.57%) was lower than the control (61.33%), and similar fat content was found between the control (7.60%) and the treatment (8.07%). Although this result was not statistically strong enough to show the significance of fat and moisture content, it indicated that the absorption of oil might be similar compared with the control and the treatment during the par-frying, and the loss of moisture might be higher for the treated nuggets. Therefore, the lower par-fry yield in the treated nuggets could be explained by the increased loss of moisture.

A higher moisture loss in the treated nuggets can be induced by a reduced WHC of incorporated fibers during the par-frying process. In the supplementation of fiber for the treated nuggets, 70% was IMO and 30% was HPMC. The low molecule weight fiber, IMO, is highly water-soluble with 100% solubility (Bioneutra North America Incorporation, 2014). Based on the observation of the aqueous solution of the same concentration (1%) in room temperature, the viscosity of IMO solution is much lower than the HPMC one that is a thickening agent with a high molecule weight, may indicating that HPMC has a higher effect on the WHC of meat block.

Hydroxypropyl methylcellulose can be solubilized in cold water by swelling and subsequent hydration, but its solubility is low at 30C and is negligible at more than 35-40C (Kolanowski et al., 2004). Information from The Dow Chemical Company (2002) indicated that the viscosity of an aqueous solution made up of 2% HPMC product decreased quickly with increasing temperature until gelation temperature is reached. The gelation temperature is highly affected by the concentration of HPMC; generally the higher the concentration is, the lower gelation temperature is (The Dow Chemical Company, 2002). For example, the 2% aqueous solution of METHOCEL K4M was 84C, and an increase of 2% in the concentration of METHOCEL A type can cause a 10C drop in the gelatin temperature (The Dow Chemical Company, 2002). The type of METHOCEL products depends on the degree of substitution of hydroxyl groups from celluloses by methyl and hydroxypropyl groups, and the degree of polymerization (Silva et al., 2008). METHOCEL K100M used in this study has a high degree of substitution and polymerization, indicating that it has a higher gelation temperature and a higher

viscosity compared with other types of HPMC product at the same concentration in the solution (The Dow Chemical Company, 2002). In addition, additives such as glycerin, sorbitol, and salts can reduce the gelation temperature by the solubilizing effect, resulting in a more rapid dehydration (The Dow Chemical Company, 2002). Therefore, the salts, phosphates and IMO in the meat block may reduce the gelation temperature of METHOCEL K100M, so may the high concentration of HPMC.

Based on Table 2, 2.03% HPMC was added in the meat block containing 7.03% water and 53.84% ground breast meat. According to USDA Agricultural Research Service (2015), the water content of boneless skinless breast meat is 73.6%. So the maximum water that could be used to hydrate HPMC is 46.65% in the meat block, which means that the lowest concentration of HPMC solution in the meat block is 4.35% if all HPMC was soluble in the available water. But this concentration is still lower than the solubility limit of high-viscosity HPMC products (METHOCEL K type) that was at 2-3% concentration (The Dow Chemical Company, 2002). Therefore, most HPMC was not soluble in the water of the meat block.

Based on the change of the viscosity of HPMC solution, it indicates that the heating process reduces the interaction between water and HPMC, resulting in the dehydration until the viscosity increases rapidly as the incipient gelation temperature is reached. With the current nugget process, the HPMC began to be solubilized in the water during the mixing step when the meat paste was cold. However, due to the limited solubility of HPMC (The Dow Chemical Company, 2002), most of HPMC still was in the solid state in the meat block. The dissolved HPMC combined with the added water

by swelling and hydration before par-frying process. During the par-frying, the solubility of HPMC around the meat block surface may have decreased rapidly with the increased temperature, so may the viscosity of HPMC solution. With less HPMC combining water and reduced interaction between HPMC and water, water evaporated more quickly during the heating process. This explanation could be the cause of the lower par-fry yield in the treatment group. However, if HPMC is added to the batter or pre-dust, HPMC will be hydrated by the water to form an interfacial gel which could act as a coating or a barrier film to create a barrier of oil absorption and moisture loss in fried products (Pearson and Gillett, 1996). In Chen et al. (2008), HPMC was added at 2% of HPMC to the batter ingredients of mackerel nuggets and the results indicated that there was less water loss in HPMC-coated nuggets when deep fried. It was concluded that HPMC had the ability to create a barrier of water diffusion. Moreover, Sahin et al. (2005) and Jamshidi and Shabanpour (2013) also found higher moisture content and lower lipid content in HPMC-coated nuggets after frying process.

For cook loss, no significant difference was found compared with control (4.56%) and the treatment nuggets (4.27%). This lack of difference indicates that the moisture loss was similar during oven cooking between control and the treated nuggets. As mentioned in the previous discussion, HPMC has a higher WHC affect compared with IMO due to the obvious difference of the viscosity of same solution, so HPMC plays a bigger role in affecting the cook loss results. During the baking process, HPMC could form a thermo-reversible gel upon heating which could reduce the moisture loss by the gel film in the meat block for the treated nuggets; however, the results of this study

indicated no significant difference was found between the control and the treatment. This could be due to HPMC losing bound water during the heating process before gelling and formed a gel with low hydration by the time that the temperature reached the gel point. Because the solubility and WHC of HPMC decreased with increased temperature before the gelling (The Dow Chemical Company, 2002), indicating that a large amount of water may be lost before the formation of gel in the treated nuggets. The results indicated that the moisture loss may be similar to that experienced by the denaturation of meat protein during cooking. In a study by Hill and Prusa (1988), no significant difference was found in the cook loss for lean ground beef patties with the addition of 0.5% and 1.0% HPMC when compared to the control without HPMC addition. In other studies about the incorporation of dietary fiber products in the meat block of chicken nuggets, the results indicated that the fibers extended in the meat block did not maintain as much water as the replaced meat proteins. In the study conducted by Prinyawiwatkul et al. (1997), flours processed from fermented cowpeas and fermented partially defatted peanuts were incorporated at 20% in the core part of treated chicken nuggets respectively. Higher moisture content was found after frying in control nuggets when compared with the treated nuggets. In another study by Verma et al. (2010), apple pulp was added to the core portion of treatment chicken nuggets at 8%, 10% and 12%, but lower cooking yields were found in all three treatments compared with the control, indicating that water loss was higher for the treatment.

When measuring the yield loss of the frozen nuggets, after 24 hr of freezing, the treatment had a lower ($P < 0.05$) freeze loss (1.46%) compared with the control (1.82%),

indicating that the treatment retained more water during the freezing. The major water loss is from the evaporation of water during the cooling process and the sublimation of ice from the product during frozen storage (Rao and Novak, 1977). After cooking, meat proteins are denatured resulting in the loss of major function of binding water (Tornberg, 2005). Hydroxypropyl methylcellulose is heat stable and will become soluble again in water upon cooling because it forms a thermo-reversible gel (The Dow Chemical Company, 2002). The viscosity of HPMC solution is high in the cold condition, indicating that HPMC can retain water before and during freezing. Moreover, IMO is a heat stable oligosaccharide and can be functioned as a humectant in food product to retain moisture, which could also reduce the moisture loss in the frozen storage. Therefore, the significant decrease in freeze loss in the treatment is most likely due to the WHC of HPMC and IMO. In a study by Bárcenas and Rosell (2006), bread containing 0.5% HPMC (flour basis) had higher moisture content both in a positive temperature cold storage and a frozen storage, compared with the control that did not contain HPMC.

The final yield represents the most important calculated yield for the manufacturing industry as it represents the total amount of sellable product based from the initial input of meat. Labeling regulation for ingredients and coated products are also based on the final yield "packaged weight". There was no significant difference found in the final yield between the treatment (19.16%) and control (19.45%). This indicates that both products produced similar yield ($P > 0.05$) after coating, par-frying, oven cooking,

and freezing. Therefore, the addition of HPMC and IMO in the treated nuggets did not affect overall final yield of the product.

Color evaluation

The color values (L*, a* and b*) of meat block region were measured to determine any negative consumer acceptance concerns (Table 3). A total of 50 nuggets, in two replications, were used for color determination. The treatment nuggets were darker as indicated by lower L* values ($P < 0.05$) and more yellow as indicated by higher b* values ($P < 0.05$) than the control, but had the similar redness as indicated by no differences in a* value ($P > 0.05$) when compared to the control.

Table 3. Mean and Standard Deviation of CIELAB[1] Color Space Values on Control and Fiber-added Soy Chicken Nuggets Meat Block

Treatment[2]	L*	a*	b*
Control	78.29±0.17	0.48±0.04	12.09±0.10
Treatment	76.97±0.17	0.46±0.04	12.76±0.09
P value	< 0.0001	0.6699	< 0.0001

[1] CIELAB: CIE L*a*b*

[2] Means were calculated from 25 nuggets collected over 2 replications (n=50); significant difference was found when $P < 0.05$.

Lightness represents the reflection of light and is highly affected by fat content and extracellular water of the meat product. Higher fat content with a higher proportion of white fat, one major type of adipose tissue, in the meat block can produce lighter meat products (Mittal and Barbut, 1994). In this experiment, breast meat was trimmed to remove fat prior to processing the nuggets. In addition, similar fat content was found compared with the control (7.60%) and the treatment (8.07%) in the small test

mentioned in the previous yield discussion, indicating that fat content is probably not a major factor influencing lightness. However, increased extracellular water can increase the refraction of light, leading to a higher L* value, while an increase in bound water (intracellularly), can absorb light resulting in a darker color and a lower L* value (Barbut, 2001). The treatment had a lower L* values which could be due to the binding between HPMC and water in the meat structure. After reheating the frozen nuggets to 74C, nuggets were cooled to room temperature prior to the analysis. In room temperature (21C), HPMC started to be soluble in the water again to increase the viscosity because of the thermo-reversible gel formed (The Dow Chemical Company, 2002). It indicated that HPMC could combine with the water, resulting in less extracellular water in the treated meat block. This reduced extracellular water resulted in the decreased refraction and higher absorption of light or lower ($P < 0.05$) L* values for treated nuggets (76.79) when compared with the control (78.29). Although, a statistical difference was observed from the objective measurements of the colorimeter, under real life conditions, consumers will be unable to distinguish small changes in lightness in cooked products.

The positive a* value represents the redness in the meat block which can be influenced by the myoglobin content in the cooked meat. Broiler boneless skinless breast meat has a low content of myoglobin due to the high amount of slow-twitch fiber types present. The incorporation of ingredients may impart red hues that change the values of a* when compared to breast meat samples. The results indicated that there was no difference ($P > 0.05$) in redness between the control (0.48) and the treatment (0.46) even after the addition of fiber products in the treated nuggets. The incorporation of HPMC

and IMO fiber into the treated meat block of the fully cooked nuggets did not impart a change to the redness (a*) value.

A positive b* value represented the intensity in yellowness of the meat sample. The incorporation of ingredients may impart yellowness hues that change the values of b* when compared to breast meat samples. When the sampled nuggets were tested for b* values, the treatment (12.79) were more yellow ($P < 0.05$) when compared with the control (12.09). The hydrated TSPC has a natural yellow color that may be the main source of yellow color in the soy chicken nuggets. The replacement of ~7% breast meat by fiber products, and the increased proportion of the hydrated soy protein to meat, from the meat block, may have caused a significantly more yellow product. Although, a statistical difference was observed from the objective measurements of the colorimeter, under real life conditions, consumers will be unable to distinguish small changes in yellowness of cooked products.

Table 4. Mean and Standard Deviation in Shear Force of Control and Fiber-added Soy Chicken Nuggets

Treatment[1]	Shear force (N)
Control	13.73 ±0.36
Treatment	7.17 ±0.25
P value	< 0.0001

[1] Means were calculated from 25 nuggets collected over 2 replications (n=50); significant difference was found when $P < 0.05$.

Shear force

Shear force represents the force need to be applied perpendicular to the object to create a cut through the sample. Shear force measures the tenderness of meat products, which is the most important factor to determine the meat quality (Pearson, 2013). The temperature of the sample will affect the readings of shear force, which should be controlled to improve the repeatability. Gums are temperature-sensitive substances, for example the viscosity of HPMC solution decreases with increased temperature (The Dow Chemical Company, 2002). The maximum shear force required to slice the nugget cubes was recorded in Table 4. A total of 50 measurements, in two replications, were used from each treatment. The control nuggets (13.73 N) had a higher ($P < 0.05$) shear force compared with the treatment (7.17 N) indicating the controls were less tender than the treated nuggets. This difference in texture could be due to the fiber products, especially HPMC, which forms a thermo-reversible gel during the cooking step by the hydrophobic interaction between the molecules containing methoxyl group (Silva et al., 2008). When nuggets were cooled (4C) prior to testing, the hydrophobic interaction reduces in the thermo-reversible HPMC gel and HPMC becomes soluble in cold water again to form solution which has a tender texture than the gel (The Dow Chemical Company, 2002). Meantime, HPMC forms a weaker and softer gel upon heating when temperatures increased above 63 to 80C compared with methylcellulose (MC), due to the interference of hydroxypropyl group on the interaction of methoxyl group (Saha and Bhattacharya, 2010). Moreover, the incorporation of gums may interfere with the binding among the meat particles (Mittal and Barbut, 1994). Hill and Prusa (1988)

reported that the addition of HPMC to lean ground beef patties reduced the amount of force to compress the core. A more tender texture was also found in the chicken nuggets that were incorporated with dietary fiber products in the core portion (Verma and Banerjee, 2010). Prinyawiwatkul et al. (1997) reported lower peak forces in the chicken nuggets incorporated with fermented cowpea and peanut flours compared with control. Therefore, the addition of the HPMC gum as well as other fiber sources could result in the increased tenderness in the treated nuggets. Although statistical difference in shear force was found between the control and the treatment, the texture of treatment was still acceptable by the tasting from lab sensory group.

Fiber content

Fiber can be defined in many ways but generally is considered as indigestible carbohydrates that do not provide any nutritional or energetic source to human. All manufactured foods must include a nutritional table in their label. Fiber is one of the nutrients that are included in the table. Fiber is usually identified as TDF which is further classified into SDF and IDF.

According to 21 CFR part 101 (FDA, 2015), if a soy chicken nugget has more than 2.5 g of TDF per serving, it can be claimed in the label as a "Good Source" of fiber. Three g of TDF per serving, a serving being 87g for 3 fully cooked frozen soy chicken nuggets, was designed as a target. To achieve the target, two types of soluble fibers, HPMC (30%) and IMO (70%) were added to the fiber treated nuggets. The results for fiber content in the control and fiber treated soy chicken nuggets are shown in Table 5. After analysis following the AOAC Official Methods 985.25 and 991.43, similar fiber

Table 5. Fiber Content of Control and Fiber-added Soy Chicken Nuggets Measured by AOAC[1] Official Methods 985.25 and 991.43 and AOAC Official Methods 2009.01 and 2011.25

Analysis[2]	Fiber Content Methods							
	AOAC Official Methods 985.25 and 991.43				AOAC Official Methods 2009.01 and 2011.25			
	Control		Treatment		Control		Treatment	
	Percent[3]	g/serving[4]	Percent	g/serving	Percent	g/serving	Percent	g/serving
TDF	2.41	2.10	2.50	2.18	2.50	2.18	3.34	2.91
SDF	0.888	0.77	0.762	0.66	1.24	1.08	2.35	2.04
IDF	1.52	1.32	1.74	1.51	1.26	1.10	0.985	0.86

[1] AOAC: Association of Official Analytical Chemists

[2] TDF: Total dietary fiber; SDF: Soluble dietary fiber; IDF: Insoluble dietary fiber; measurements were performed on 1 composite sample of 5 nuggets (n=1).

[3] Based on the weight of final soy chicken nuggets

[4] Serving size was 87 g with three pieces of soy chicken nuggets

contents (TDF, SDF and IDF) were observed between the control (2.10, 0.44, and 1.32 g/serving; respectively) and the fiber treated nuggets (2.18, 0.66, and 1.51 g/serving; respectively). These results indicate that there was no supplementation of fiber in the fiber-added treatment compared to the control nuggets. The fibers detected were mostly insoluble fiber for both the control and the treatment, with an average ratio of the insoluble to soluble fiber being 2:1. The detected fibers are possibly from two major sources, TSPC and coating ingredients. According to the nutrition fact of TSPC, there is 12 g insoluble fiber and 6 g soluble fiber in 100 g dry product (Solae Limited Liability Company, 2014), which is similar to the ratio of the insoluble fiber to the soluble fiber in the results. According to the formulation, 30% of hydrated TSPC was added to the meat block with the hydration ratio of 3:1 (water: TSPC). Theoretically, the addition of TSPC results in 0.99 g TDF, 0.66 g IDF and 0.33 g SDF per serving in the final product for both control and treatment. The other fibers could be from batter and breading ingredients, containing a little more than1 g dietary fiber per serving that is similar to the fiber content in commercial all-meat chicken nuggets. The AOAC Official Methods 985.25 and 991.43 cannot detect low molecule weight soluble dietary fiber (LMWSDF) including IMO that does not precipitate in 78% aqueous ethanol (AOAC International, 2012a,b). While HPMC should have been detected by this method (AOAC 985.25 and 991.43), since HPMC can precipitate in the 78% aqueous ethanol. The supplementation level of functional fibers in treated nuggets was 3 g per serving, which composed of 2.1g IMO and 0.9 g HPMC per serving. So theoretically, using AOAC 985.25 and 991.43, an increase of 0.9 g per serving in both TDF and SDF from HPMC should have been found

in the treatment compared with the control. However, the results received from the laboratory indicated that the control and treatment were similar in TDF and SDF.

To detect IMO, the samples were analyzed by another method, AOAC Official Methods 2009.01 and 2011.25. The results (Table 5) indicated that the fiber treated nuggets had 2.91 g of TDF per serving, which could be labeled as a "Good Source" of fiber. In addition, most of these fibers were soluble (2.04 g per serving). The control nuggets obtained 2.18 g of TDF per serving, which was similar to the results seen on the control nuggets using the previous method (AOAC 985.25 and 991.43). These results indicated that the results of both methods were similar when no LMWSDF was present in the product. The results further suggest that 0.73 g of TDF per serving was supplemented in the fiber treated nuggets, and that the majority of the fiber was from soluble fiber, with an increase of 0.96 g of SDF per serving. Upon further investigation, the AOAC Official Methods 2009.01 and 2011.25 was found to be able to detect LMWSDF (Table 6), which was undetectable by AOAC Official Methods 985.25 and 991.43. However, the result of the detected fiber supplementation (0.73 g of TDF per serving) was still much lower than the fiber supplemented based on the nugget formula of 3.0 g of TDF per serving. Based upon this new AOAC Methods, LMWSDF was undetectable (< 0.50%) in the control and the fiber treated nuggets had 1.05 g of LMWSDF per serving. These LMWSDF results were expected for the control nugget, since no IMO was supplemented to the control nugget. However, for the treated nugget, the value (1.05 g of LMWSDF per serving) was still much lower than the supplemented level (2.1 g of LMWSDF per serving), since 70% of fiber supplementation (3 g per

serving) was IMO (LMWSDF). According to the principle of the new method, HPMC should be included as soluble dietary fiber precipitate (SDFP) that is water soluble but water: alcohol insoluble, and is precipitated by ethanol from the filtrate and washed water of IDF (AOAC International, 2012a,b). As the previous discussion, a 0.9 g of HPMC per serving was supplemented in the treated nugget compared with the control, which should have resulted in the same increase in SDFP. But the results (Table 6) showed that SDFP was similar between the control (1.24%) and the treated nuggets (1.14%), therefore indicating that no HPMC was detected from the treated nuggets by the new method (AOAC 2009.01 and 2011.25). Above all, HPMC was undetected by both AOAC methods, and less than half of IMO (LMWSDF) was able to be measured by AOAC Official Methods 2009.01 and 2011.25.

Table 6. Fiber Content of Control and Fiber-added Soy Chicken Nuggets Measured by AOAC[1] Official Methods 2009.01 and 2011.25

Analysis[2]	Control		Treatment	
	Percent[6]	g/serving[7]	Percent	g/serving
TDF[3]	2.50	2.18	3.34	2.91
SDF[4]	1.24	1.08	2.35	2.04
IDF	1.26	1.10	0.985	0.86
HMWDF[5]	2.50	2.18	2.13	1.85
LMWSDF	< 0.500	< 0.44	1.21	1.05
SDFP	1.24	1.08	1.14	0.99

[1] AOAC: Association of Official Analytical Chemists
[2] TDF: Total dietary fiber; SDF: Soluble dietary fiber; IDF: Insoluble dietary fiber; HMWDF: High molecule weight dietary fiber; LMWSDF: Low molecule weight soluble dietary fiber; SDFP: Soluble dietary fiber precipitate; measurements were performed on 1 composite sample of 5 nuggets (n=1).
[3] TDF=HMWDF+LMWSDF
[4] SDF=LMWSDF+SDFP
[5] HMWDF=IDF+SDFP
[6] Based on the weight of final soy chicken nuggets
[7] Serving size was 87 g with three pieces of soy chicken nuggets

To try to determine the reasons for the low fiber content results in the fiber supplemented nuggets. The HPMC and IMO powder products (METHOCEL K100M and VitaFiber^{TM}) used in the study, and blank raw treatment nuggets without breading was measured for TDF, SDF and IDF by AOAC Official Methods 2009.01 and 2011.25 (Table 7). The results indicated that the HPMC product was reported to have "matrix interference" due to a filtering issue caused by the solution thickening ability of HPMC. The result also indicated that there were only 23.6% of TDF based on dry IMO product and all of it was LMWSDF (IMO). For the fiber treated blank nuggets, a similar TDF result (3.25%) was found when compared with the breaded treatment nuggets (3.34%) in Table 5 by the same method. Also, the blank nuggets were found to have a slightly higher IDF and lower SDFP when compared with the breaded treatment nuggets. These results could possibly indicate that the ingredients of the commercial batter and breader ingredients used may contain higher contents of high molecule weight soluble dietary fiber. In addition, 5.75% of IMO product was added to the meat block of the treatment based on the formula (Table 1), and only 23.6% of LMWSDF (IMO) was able to be detected from IMO product (Table 7). So to multiply these two percentages, it could be concluded that the theoretical and detectable IMO content in blank treatment nugget should be 1.36% which was similar to the LMWSDF content (1.25%) in the blank treatment nugget in Table 7. These results may indicate that the IMO didn't lose during the mixing, cooling, forming, and crust-freezing. Moreover, the content of HPMC in HPMC product is on less than 85% (The Dow Chemical Company, 2014), and 2.03% of HPMC product was added to the meat block of the treatment based on the formula

(Table 1). So to multiply these two results, it could be concluded that the supplemented level of HPMC in the blank treatment nugget was 1.73%, which was much higher than the SDFP content (0.47%) in the result of blank treatment nugget. Therefore, these results along with the previous conclusions indicated that HPMC was probably undetected from AOAC Official Methods 2009.01 and 2011.25.

Table 7. Fiber Content of HPMC[1] Product, IMO[2] Product and Blank Treatment Nuggets Measured by AOAC[3] Official Methods 2009.01 and 2011.25

Analysis[4]	HPMC product Percent[8]	IMO product Percent	Blank treatment nugget[9] Percent
TDF[5]	Matrix interference	23.6	3.25
SDF[6]	Matrix interference	23.6	1.72
IDF	Matrix interference	< 0.750	1.53
HMWDF[7]	Matrix interference	< 0.750	2.01
LMWSDF	Matrix interference	23.6	1.25
SDFP	Matrix interference	< 0.750	0.47

[1] HPMC: Hydroxypropyl methylcellulose
[2] IMO: Isomalto-oligosaccharide
[3] AOAC: Association of Official Analytical Chemists
[4] TDF: Total dietary fiber; SDF: Soluble dietary fiber; IDF: Insoluble dietary fiber; HMWDF: High molecule weight dietary fiber; LMWSDF: Low molecule weight soluble dietary fiber; SDFP: Soluble dietary fiber precipitate; measurements were performed on 1 composite sample of 5 nuggets (n=1) for IMO and HPMC product
[5] TDF=HMWDF+LMWSDF
[6] SDF=LMWSDF+SDFP
[7] HMWDF=IDF+SDFP
[8] Based on the initial weight of product
[9] Unbreaded nuggets formulated with HPMC and IMO measurements were performed on a duplicate sample of a 5 blank nuggets per composite (n=1)

The reasons that HPMC was undetectable in both methods may be the thickening property of HPMC. The composition of HPMC product is 85.0% to 99.0% HPMC, 0.5% to 5.0% sodium chloride, and 1.0% to 10.0% water (The Dow Chemical Company, 2014). Due to the thickening property of HPMC, it was problematic to filter when

HPMC aqueous solution. Therefore, during the analysis, it may be difficult to separate HPMC from IDF residue into the filtrate when the digestate was filtered and IDF residue was rinsed by water. This filtrate was then precipitated by ethanol and the precipitate was measured as SDFP. Therefore, this may be the reason almost no HPMC was detected in SDFP. To prevent this issue, AOAC Official Method 2006.08 has been developed to measure the content of HPMC and methylcellulose (MC) gums. Essentially, methylcellulose food gum (MFG) containing HPMC and MC are hydrated first, and then the samples are analyzed by liquid chromatography to determine the content. This method is able to measure the MFG content in food product that doesn't have co-eluting other soluble polysaccharides (AOAC International, 2007).

For measuring the IMO content in IMO product, there are 91 g of TDF in a 100 g sample as measured by a validated HPLC-RI method based on the nutritional information of the IMO product (Bioneutra North America Incorporation, 2014). The nutritional information also points out that 50% TDF content can be detected using AOAC Official Method 2009.01 (Bioneutra North America Incorporation, 2014). However, the results of Table 7 indicated only 23.6% TDF content was found by AOAC Official Methods 2009.01 and 2011.25, which was considerably less than the claimed content (50%). The reason may be that the amyloglucosidase for removing starch during the analyzing could also digest α-(1, 6) linkage, leading to some degradation of IMO. To address this issue, a high-performance liquid chromatographic method with a polymer-based amino column was developed to measure IMO content in commercial IMO products (Nakanishi et al., 2006). In this method, individual IMO compounds, such as

iosmaltose, isomaltotriose, isomaltotetraose, and panose, were measured using the calibration curve of refraction-index detector response against a concentration of standard IMO and maltosaccharide reagents.

The limitations of the currently available fiber methods could be the major reason for the lower fiber results. Another explanation may be that some fiber was lost during the processing. Due to the failure to measure accurately HPMC by these two methods, no evidence could prove that some part of HPMC was lost during the process. Alternatively, it could be reasoned that HPMC existed in the final product because of the gummy texture of the treated nuggets after cooling. During the process, HPMC was first dispersed in the meat batter and some HPMC became soluble in the ice water during the mixing, but most HPMC was still in solid state due to the limitation of solubility. The dissolved HPMC was hydrated to create a high-viscosity solution during the mixing, cooling, forming, and coating processes, because of the low temperature in meat block. When par-frying, the HPMC that was close to the meat block surface began to precipitate because of the reduced solubility by heating. While the temperature of core region was still very cold (close to 0C) after par-frying indicating that HPMC was still hydrated with water in the meat block. Then during the oven cooking, the solubility was continuously decreasing alongside the WHC of HPMC with the increase in internal temperature of the meat block. Increased moisture was lost until the gel point was reached (above 50C), forming a thermo-reversible gel. Following cooling and freezing, HPMC became soluble in water again and some HPMC may come out with condensed water. The other product IMO is highly soluble in water, functioned as a sweetener.

From the previous conclusion, IMO did not have a high loss during the mixing, cooling, forming, and crust-freezing by comparing the LMWSDF content in blank treatment nugget (1.25%) to the theoretical IMO content (1.36%) based on the addition level in the formula and the LMWSDF result of IMO product. In addition, the LMWSDF content of blank treatment nugget (1.25%) in Table 7 is divided by the ratio of final weight to blank weight (1.1916) that is based on the final yield parameter (19.16%) in Table 2. It could be concluded that the theoretical LMWSDF content in the final product is 1.05%, which was lower than the LMWSDF content (1.21%) in the final treatment nugget in Table 6. These results indicate that no IMO was lost during the heating and frozen storage. Therefore, the explanation of the loss of fiber during processing possibly may not be the major reason of low fiber content.

Above all, the limitations of AOAC Official Methods 985.25 and 991.43 and AOAC Official Methods 2009.01 and 2011.25 resulted in much lower fiber content than the supplementation level in the formula. More accurate and convenient fiber methods need to be developed and modified to provide more reliable and stable results.

CHAPTER III

CONCLUSIONS

The incorporation of functional fibers, hydroxypropyl methylcellulose (HPMC) and isomalto-oligosaccharide (IMO), in the treatment soy chicken nuggets resulted in a lower par-fry yield ($P < 0.05$) and a lower freeze loss ($P < 0.05$), but a similar final yield of product ($P > 0.05$) compared with the control, indicating that fiber supplementation didn't affect the overall final yield in product. Although the treated nuggets were found to have a darker ($P < 0.05$) and more yellow ($P < 0.05$) color compared with the control, these statistical differences will not be able to tell by human eyes at such low threshold levels, indicating that the incorporation of functional fibers may not affect the consumers' preference of color. Also the treated nuggets had a more tender ($P < 0.05$) texture compared with the control. Extreme tenderness in meat products is undesirable; however, the texture of treated nuggets was still acceptable. Therefore, based on yield parameters, color and texture, it could be concluded that the fiber-added soy chicken nugget is a similar product compared with the control, soy chicken nuggets. From the results of fiber contents, the treatment was detected to have 2.91 g of total dietary fiber (TDF) per serving by Association of Official Analytical Chemists (AOAC) Official Methods 2009.01 and 2011.25, which could be claimed as a "Good Source" of fiber. However, much lower fiber content was detected by both AOAC Official Methods 985.25 and 991.43 and AOAC Official Methods 2009.01 and 2011.25 than the targeted supplementation level due to the limitations of these two fiber methods. Both methods

were unable to measure HPMC due to filtering issue; while IMO was not included in AOAC Official Methods 985.25 and 991.43, and only 23.6% of IMO could be determined in IMO product by AOAC Official Methods 2009.01 and 2011.25, which was much less than the claim level of the IMO product (50%). Above all, functional fibers could be added in the meat block to produce an acceptable soy chicken nugget, but more precise and convenient fiber methods need be developed and modified to provide more reliable fiber contents in meat products. In the further study, HPMC can be attempted to add to the coating to increase the TDF content; or find another functional fiber that is more easily detected and beneficial, to replace HPMC and IMO to optimize the performance and quality in meat block of soy chicken nuggets,

REFERENCES

Altunakar, B., S. Sahin, and G. Sumnu. 2006. Effects of hydrocolloids on apparent viscosity of batters and quality of chicken nuggets. Chemical engineering communications 193:675-682.

Anderson, J. W., P. Baird, R. H. Davis, S. Ferreri, M. Knudtson, A. Koraym, V. Waters, and C. L. Williams. 2009. Health benefits of dietary fiber. Nutrition reviews 67:188-205.

Applewhite, T. H. 1989. Proceedings of the World Congress on vegetable protein utilization in human foods and animal feedstuffs. The American oil chemists society.

Association of Official Analytical Chemists [AOAC] International. 2005a. AOAC official method 985.29: Total dietary fiber in foods. In AOAC Official Methods of Analysis. 18th ed. Association of Official Analytical Chemists, Gaithersburg, MD.

Association of Official Analytical Chemists [AOAC] International. 2005b. AOAC official method 991.43: Total, soluble and insoluble dietary fiber in foods. In AOAC Official Methods of Analysis. 18th ed. Association of Official Analytical Chemists, MD.

Association of Official Analytical Chemists [AOAC] International. 2007. AOAC official method 2006.08: Methylcellulose and hydroxypropyl methylcellulose food gums in food and food products. In AOAC Official Methods of Analysis. 18th ed. Association of Official Analytical Chemists, Gaithersburg, MD.

Association of Official Analytical Chemists [AOAC] International. 2012a. AOAC official method 2009.01: Total dietary fiber in foods. In AOAC Official Methods of Analysis. 19th ed. Association of Official Analytical Chemists, Gaithersburg, MD.

Association of Official Analytical Chemists [AOAC] International. 2012b. AOAC official method 2011.25: Total, soluble and insoluble dietary fiber in foods. In AOAC Official Methods of Analysis. 19th ed. Association of Official Analytical Chemists, Gaithersburg, MD.

Barbut, S. 2001. Poultry products processing: an industry guide. CRC Press, Boca Raton, FL.

Bárcenas, M. E., and C. M. Rosell. 2006. Different approaches for improving the quality and extending the shelf life of the partially baked bread: low temperatures and HPMC addition. Journal of food engineering 72:92-99.

Bioneutra North America Incorporation. 2014. Assessed 2014. VitaFiber Factsheet. http://www.bioneutra.ca/_pdf/VitaFiber_FactSheet.pdf.

Bouhnik, Y., L. Raskine, G. Simoneau, E. Vicaut, C. Neut, B. Flouri é, F. Brouns, and F. R. Bornet. 2004. The capacity of nondigestible carbohydrates to stimulate fecal bifidobacteria in healthy humans: a double-blind, randomized, placebo-controlled, parallel-group, dose-response relation study. The American journal of clinical nutrition 80:1658-1664.

Brown, L., B. Rosner, W. W. Willett, and F. M. Sacks. 1999. Cholesterol-lowering effects of dietary fiber: a meta-analysis. The American journal of clinical nutrition 69:30-42.

Burger King Corporation. 2015. Chicken nuggets. Accessed 2015. http://www.bk.com/menu-item/chicken-nuggets.

Carr, T. P., and D. D. Gallaher. 1996. Increased intestinal contents viscosity reduces cholesterol absorption efficiency in hamsters fed hydroxypropyl methylcellulose. The journal of nutrition 126:1463.

Champ, M., A. M. Langkilde, F. Brouns, B. Kettlitz, and Y. L. B. Collet. 2003. Advances in dietary fibre characterisation. 1. Definition of dietary fibre, physiological relevance, health benefits and analytical aspects. Nutrition research reviews 16:71-82.

Chen, C., P. Li, W. Hu, M. Lan, M. Chen, and H. Chen. 2008. Using HPMC to improve crust crispness in microwave-reheated battered mackerel nuggets: Water barrier effect of HPMC. Food hydrocolloids 22:1337-1344.

Chen, H., and Y. Huang. 2008. Rheological properties of HPMC enhanced surimi analyzed by small-and large-strain tests—II: Effect of water content and ingredients. Food hydrocolloids 22:313-322.

Chen, H., Y. Lu, J. Lin, and L. Ko. 2001. Effects of isomalto-oligosaccharides on bowel functions and indicators of nutritional status in constipated elderly men. Journal of the American college of nutrition 20:44-49.

Choe, E., and D. Min. 2007. Chemistry of deep-fat frying oils. Journal of food science 72:R77-R86.

Clemens, R., S. Kranz, A. R. Mobley, T. A. Nicklas, M. P. Raimondi, J. C. Rodriguez, J. L. Slavin, and H. Warshaw. 2012. Filling America's fiber intake gap: summary of a roundtable to probe realistic solutions with a focus on grain-based foods. The journal of nutrition 142:1390S-1401S.

Dana, D., and I. S. Saguy. 2006. Review: mechanism of oil uptake during deep-fat frying and the surfactant effect-theory and myth. Advances in colloid and interface science 128:267-272.

Davidson, M. H., L. D. Dugan, J. H. Burns, J. Bova, K. Story, and K. B. Drennan. 1991. The hypocholesterolemic effects of β-glucan in oatmeal and oat bran: a dose-controlled study. Jama 265:1833-1839.

Davidson, M. H., L. D. Dugan, J. H. Burns, D. Sugimoto, K. Story, and K. Drennan. 1996. A psyllium-enriched cereal for the treatment of hypercholesterolemia in children: a controlled, double-blind, crossover study. The American journal of clinical nutrition 63:96-102.

Dressman, J. B., C. H. Adair, J. L. Barnett, R. R. Berardi, V. A. Dunn-Kucharski, K. M. Jarvenpaa, D. D. Parr, C. A. Sowle, S. Z. Swidan, and S. W. Tobey. 1993. High-molecular-weight hydroxypropylmethylcellulose: a cholesterol-lowering agent. Archives of internal medicine 153:1345-NP.

Dušek, M., F. Kvasnička, L. Lukášková, and J. Krátká. 2003. Isotachophoretic determination of added phosphate in meat products. Meat science 65:765-769.

Eastwood, M. A., and E. R. Morris. 1992. Physical properties of dietary fiber that influence physiological function: a model for polymers along the gastrointestinal tract. The American journal of clinical nutrition 55:436-442.

Feiner, G. 2006. Meat products handbook: Practical science and technology. Woodhead Publishing Limited, UK.

Fernandez, M. L., and D. Webb. 2008. The LDL to HDL cholesterol ratio as a valuable tool to evaluate coronary heart disease risk. Journal of the American college of nutrition 27:1-5.

Fillion, L., and C. Henry. 1998. Nutrient losses and gains during frying: a review. International journal of food sciences and nutrition 49:157-168.

Food and Drug Administration [FDA]. 2005. GRAS Notice: Isomalto-oligosaccharide. Accessed Jul., 25, 2005. http://www.fda.gov/ucm/groups/fdagov-public/@fdagov-foods-gen/documents/document/ucm268863.pdf.

Food and Drug Administration [FDA]. 2015. Nutrition labeling of food. 21 CFR part 101. Fed. Regist. 9:19-46.

Gallaher, D. D., C. A. Hassel, and K. Lee. 1993. Relationships between viscosity of hydroxypropyl methylcellulose and plasma cholesterol in hamsters. Journal of nutrition-Baltimore and Springfield then Bethesda-123:1732.

Goffin, D., N. Delzenne, C. Blecker, E. Hanon, C. Deroanne, and M. Paquot. 2011. Will isomalto-oligosaccharides, a well-established functional food in Asia, break through the European and American market? The status of knowledge on these prebiotics. Critical reviews in food science and nutrition 51:394-409.

Gu, Q., Y. Yang, G. Jiang, and G. Chang. 2003. Study on the regulative effect of isomaltooligosaccharides on human intestinal flora. Wei sheng yan jiu= Journal of hygiene research 32:54-55.

Hayakawa, K., K. Ando, N. Yoshida, A. Yamamoto, A. Matsunaga, M. Nishimura, M. Kitaoka, and K. Matsui. 2000. Determination of saccharides in sake by high-performance liquid chromatography with polarized photometric detection. Biomedical chromatography 14:72-76.

Hesta, M., J. Debraekeleer, G. Janssens, and R. De Wilde. 2001. The effect of a commercial high-fibre diet and an isomalto-oligosaccharide supplemented diet on post-prandial glucose concentrations in dogs. Journal of animal physiology and animal nutrition 85:217-221.

Hill, S., and K. Prusa. 1988. Physical and sensory properties of lean ground beef patties containing methylcellulose and hydroxypropylmethylcellulose1. Journal of food quality 11:331-337.

Holy, M. K., and J. D. Goldman. 2014. Fiber intake of the U.S. population: what we eat in America, NHANES 2009-2010. in Food surveys research group dietary data brief No. 12.

Horan, F. E. 1974. Soy protein products and their production. Journal of the American Oil Chemists' Society 51:67A-73A.

Institute of Medicine. 2005. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Pages 340 in Dietary, Functional, and Total Fiber. The National Academies Press, Washington, DC.

Jamshidi, A., and B. Shabanpour. 2013. The effect of hydroxypropyl methylcellulose (HPMC) gum added to predust and batters of Talang Queen fish (Scomberoides commersonnianus) nuggets on the quality and shelf life during frozen storage (-18C). World 5:382-391.

Kaneko, T., T. Kohmoto, F. Fukui, T. Akiba, S. Suzuki, A. Hirao, S. Nakatsuru, and M. Kanisawa. 1990. Acute and chronic toxicity and mutagenicity studies on isomaltooligosaccharides, and the effects on peripheral blood lymphocytes and intestinal microflora. Shokuhin Eiseigaku Zasshi= Journal of the food hygienic society of Japan 31:394-403.

Kaneko, T., T. Kohmoto, H. Kikuchi, M. Shiota, T. Ytake, H. Iino, and K. Tsuji. 1993. Effects of isomaltooligosaccharides intake on defecation and intestinal environment in healthy volunteers. Nihon Kasei Gakkaishi= Journal of home economics of Japan 44:245-254.

Kanner, J., S. Harel, and R. Jaffe. 1991. Lipid peroxidation of muscle food as affected by sodium chloride. Journal of agricultural and food chemistry 39:1017-1021.

Kashimura, J., M. Kimura, and Y. Itokawa. 1996. The effects of isomaltulose, isomalt, and isomaltulose-based oligomers on mineral absorption and retention. Biological trace element research 54:239-250.

Kim, H., M. Turowski, W. K. Anderson, S. A. Young, Y. Kim, and W. Yokoyama. 2011. Supplementation of hydroxypropyl methylcellulose into yeast leavened all-whole grain barley bread potentiates cholesterol-lowering effect. Journal of agricultural and food chemistry 59:7672-7678.

Kim, J., J. Lim, I. Y. Bae, H. G. Park, H. G. Lee, and S. Lee. 2010. Particle size effect of *Lentinus edodes* mushroom (Chamsong-I) powder on the physicochemical, rheological, and oil- resisting properties of frying batters. Journal of texture studies 41:381-395.

Kim, Y., and W. H. Yokoyama. 2010. Physical and sensory properties of all-barley and all-oat breads with additional hydroxypropyl methylcellulose (HPMC) β-glucan. Journal of agricultural and food chemistry 59:741-746.

Kinsella, J. E. 1979. Functional properties of soy proteins. Journal of the American oil chemists' society 56:242-258.

Kita, A., G. Lisińska, and G. Gołubowska. 2007. The effects of oils and frying temperatures on the texture and fat content of potato crisps. Food chemistry 102:1-5.

Kohmoto, T., F. Fukui, H. Takaku, Y. Machida, M. Arai, and T. Mitsuoka. 1988. Effect of isomalto-oligosaccharides on human fecal flora. Bifidobacteria and microflora 7:61-69.

Kohmoto, T., F. Fukui, H. Takaku, and T. Mitsuoka. 1991. Dose-response test of isomaltooligosaccharides for increasing fecal bifidobacteria. Agricultural and biological chemistry 55:2157-2159.

Kolanowski, W., G. Laufenberg, and B. Kunz. 2004. Fish oil stabilisation by microencapsulation with modified cellulose. International journal of food sciences and nutrition 55:333-343.

Lairon, D., N. Arnault, S. Bertrais, R. Planells, E. Clero, S. Hercberg, and M. C. Boutron-Ruault. 2005. Dietary fiber intake and risk factors for cardiovascular disease in French adults. The American journal of clinical nutrition 82:1185-1194.

Liu, S., M. J. Stampfer, F. B. Hu, E. Giovannucci, E. Rimm, J. E. Manson, C. H. Hennekens, and W. C. Willett. 1999. Whole-grain consumption and risk of coronary heart disease: results from the Nurses' Health Study. The American journal of clinical nutrition 70:412-419.

Love, J. D., and A. Pearson. 1971. Lipid oxidation in meat and meat products—A review. Journal of the American oil chemists' society 48:547-549.

Lusas, E. W., and M. N. Riaz. 1995. Soy protein products: processing and use. The journal of nutrition 125:573S.

Maki, K. C., M. L. Carson, M. P. Miller, M. Turowski, M. Bell, D. M. Wilder, T. M. Rains, and M. S. Reeves. 2008. Hydroxypropylmethylcellulose and methylcellulose consumption reduce postprandial insulinemia in overweight and obese men and women. The journal of nutrition 138:292-296.

Maki, K. C., M. L. Carson, M. P. Miller, M. Turowski, M. Bell, D. M. Wilder, and M. S. Reeves. 2007. High-viscosity hydroxypropylmethylcellulose blunts postprandial glucose and insulin responses. Diabetes care 30:1039-1043.

Maki, K. C., M. H. Davidson, K. C. Malik, H. H. Albrecht, J. O'Mullane, and B. P. Daggy. 1999. Cholesterol lowering with high-viscosity hydroxypropylmethylcellulose. The American journal of cardiology 84:1198-1203.

Maki, K. C., M. H. Davidson, S. Torri, K. A. Ingram, J. O'Mullane, B. P. Daggy, and H. H. Albrecht. 2000. High-molecular-weight hydroxypropylmethylcellulose taken with or between meals is hypocholesterolemic in adult men. The journal of nutrition 130:1705-1710.

McCleary, B. V. 2014. Modification to AOAC Official Methods 2009.01 and 2011.25 to allow for minor overestimation of low molecular weight soluble dietary fiber in samples containing starch. Journal of AOAC international 97:896-901.

McDonald's Corporation. 2014. Accessed 2010. Chicken McNuggets. http://www. mcdonalds. com /us/en/food/product_nutrition.chickenfish.483.chicken-mcnuggets-4-piece.html.

Meullenet, J. F., E. Jonville, D. Grezes, and C. M. Owens. 2004. Prediction of the texture of cooked poultry pectoralis major muscle by near-infrared reflectance analysis of raw meat. Journal of texture studies 35:573-585.

Minolta, K. 1998. Precise color communication. Color control from perception to instrumentation, Osaka, Japan.

Mittal, G., and S. Barbut. 1994. Effects of carrageenans and xanthan gum on the texture and acceptability of low fat frankfurters. Journal of food processing and preservation 18:201-216.

Montonen, J., P. Knekt, R. Järvinen, A. Aromaa, and A. Reunanen. 2003. Whole-grain and fiber intake and the incidence of type 2 diabetes. The American journal of clinical nutrition 77:622-629.

Murphy, R., E. Johnson, L. Duncan, E. Clausen, M. Davis, and J. March. 2001. Heat transfer properties, moisture loss, product yield, and soluble proteins in chicken breast patties during air convection cooking. Poultry science 80:508-514.

Nakanishi, T., S. Nomura, and Y. Takeda. 2006. An improved method for the quantitative analysis of commercial isomaltooligosaccharide products using the calibration curve of standard reagents. Journal of applied glycoscience (Japan).

Ngadi, M., K. Dirani, and S. Oluka. 2006. Mass transfer characteristics of chicken nuggets. International Journal of food engineering 2.

Ohta, A., N. Osakabe, K. Yamada, Y. Saito, and H. Hidaka. 1993. Effects of fructooligosaccharides and other saccharides on Ca, Mg and P absorption in rats. Journal of Japanese society of nutrition and food science (Japan).

Owens, C. M. 2001. Coated poultry products. Poultry meat processing:227. CRC Press, Boca Ratom, FL.

Owens, C. M., C. Alvarado, and A. R. Sams. 2010. Poultry meat processing. 2nd ed. CRC Press, Boca Ratom, FL.

Pangborn, R., Z. M. Gibbs, and C. Tassan. 1978. Effect of hydrocolloids on apparent viscosity and sensory properties of selected beverages1. Journal of texture studies 9:415-436.

Pearson, A. M. 2013. Quality attributes and their measurement in meat, poultry and fish products. Springer, UK.

Pearson, A. M., and T. A. Gillett. 1996. Reduced and low fat meat products. Pages 355-371 in Processed meats. 3rd ed. Springer, UK.

Petruzziello, L., F. Iacopini, M. Bulajic, S. Shah, and G. Costamagna. 2006. Review article: uncomplicated diverticular disease of the colon. Alimentary pharmacology & therapeutics 23:1379-1391.

Prinyawiwatkul, W., K. H. McWatters, L. R. Beuchat, and R. D. Phillips. 1997. Physicochemical and sensory properties of chicken nuggets extended with fermented cowpea and peanut flours. Journal of agricultural and food chemistry 45:1891-1899.

Rao, R., and A. Novak. 1977. Causes and prevention of weight losses in frozen fishery products during freezing and cold storage. Proc. Culf Caribb. Fish. Inst 29:28-42.

Reppas, C., C. H. Adair, J. L. Barnett, R. R. Berardi, D. DuRoss, S. Z. Swidan, P. F. Thill, S. W. Tobey, and J. B. Dressman. 1993. High viscosity hydroxypropylmethylcellulose reduces postprandial blood glucose concentrations in NIDDM patients. Diabetes research and clinical practice 22:61-69.

Reppas, C., D. E. Greenwood, and J. B. Dressman. 1999. Longitudinal versus radial effects of hydroxypropylmethylcellulose on gastrointestinal glucose absorption in dogs. European journal of pharmaceutical sciences 8:211-219.

Reppas, C., S. Swidan, S. Tobey, M. Turowski, and J. Dressman. 2009. Hydroxypropylmethylcellulose significantly lowers blood cholesterol in mildly hypercholesterolemic human subjects. European journal of clinical nutrition 63:71-77.

Roberfroid, M. B. 1999. Caloric value of inulin and oligofructose. The journal of nutrition 129:1436S-1437s.

Rosenthal, A. J. 2010. Texture profile analysis–how important are the parameters? Journal of texture studies 41:672-684.

Rycroft, C., M. Jones, G. Gibson, and R. Rastall. 2001. A comparative in vitro evaluation of the fermentation properties of prebiotic oligosaccharides. Journal of applied microbiology 91:878-887.

Saguy, I. S., and D. Dana. 2003. Integrated approach to deep fat frying: engineering, nutrition, health and consumer aspects. Journal of food engineering 56:143-152.

Saha, D., and S. Bhattacharya. 2010. Hydrocolloids as thickening and gelling agents in food: a critical review. Journal of food science and technology 47:587-597.

Sahin, S., G. Sumnu, and B. Altunakar. 2005. Effects of batters containing different gum types on the quality of deep-fat fried chicken nuggets. Journal of the science of food and agriculture 85:2375-2379.

Sajilata, M., R. S. Singhal, and P. R. Kulkarni. 2006. Resistant starch–a review. Comprehensive reviews in food science and food safety 5:1-17.

Solae Limited Liability Company. 2014. Nutritional profile: Response® 4410 texture soy protein concentrate. Solae, LLC, North America, St. Louis, MO.

Sendra Nadal, E., J. López, and J. Pérez-Alvarez. 2008. Application of prebiotics and probiotics in meat products. Technological strategies for functional meat products development:117-137.

Sheng, G., D. Cai, and L. Wan. 2006. Determination of glycemic index of xylitol and isooligosaccharide [J]. Chinese journal of clinical nutrition 4.

Silva, S. M., F. V. Pinto, F. E. Antunes, M. G. Miguel, J. J. Sousa, and A. A. Pais. 2008. Aggregation and gelation in hydroxypropylmethyl cellulose aqueous solutions. Journal of colloid and interface science 327:333-340.

Singh, O., J. Singh, M. Bharti, and K. Soni. 2008. Refrigerated storage stability of chicken nuggets containing pea flour. Journal of food science and technology-Mysore 45:460-462.

Smith, J., and L. Hong-Shum. 2011. Food additives data book. 2nd ed. John Wiley & Sons, Hoboken, NJ.

Stender, S., J. Dyerberg, and A. Astrup. 2007. Fast food: unfriendly and unhealthy. International journal of obesity 31:887-890.

Stoick, S., J. Gray, A. Booren, and D. Buckley. 1991. Oxidative stability of restructured beef steaks processed with oleoresin rosemary, tertiary butylhydroquinone, and sodium tripolyphosphate. Journal of food science 56:597-600.

Swidan, S. Z., C. Reppas, J. L. Barnett, D. E. Greenwood, A. M. Tallman, S. W. Tobey, and J. B. Dressman. 1996. Ability of two comestible formulations of hydroxypropylmethylcellulose to lower serum cholesterol concentrations. European journal of pharmaceutical sciences 4:239-245.

Takaku, H. 1988. Anomalously linked oligosaccharides mixture ("Alo mixture"). Pages 215-217 in Handbook of amylase and related enzymes. Pergamon Press, Oxford.

The Dow Chemical Company. 2002. METHOCEL cellulose ethers-Technical handbook. The Dow Chemical Company, Midland, MI.

The Dow Chemical Company. 2014. Material safety data sheet: METHOCEL K100M food grade modified cellulose. The Dow Chemical Company, Midland, MI.

The Wendy's Company. 2015. Four-piece chicken nuggets. Accessed 2015. https://www. wendys. com/en-us/chicken/4-piece-chicken-nuggets.

Theuwissen, E., and R. P. Mensink. 2008. Water-soluble dietary fibers and cardiovascular disease. Physiology & behavior 94:285-292.

Tornberg, E. 2005. Effects of heat on meat proteins-Implications on structure and quality of meat products. Meat science 70:493-508.

Tsunehiro, J., T. Matsukubo, M. Shiota, and Y. Takaesu. 1997. Caries-inducing activity of the hydrogenated derivative of an isomaltooligosaccharide mixture in rats. Bioscience, biotechnology, and biochemistry 61:1317-1322.

Tyson Foods Incorporation. 2014. Chicken nuggets. Accessed 2014. http:// www.tyson. com/Products/Chicken-Nuggets.aspx.

United States Department of Agriculture [USDA] Agricultural Research Service. 2015. USDA Nutrient Database for Standard Reference, Release 28. Accessed Sep. 2015. http://ndb.nal.usda.gov/ndb/nutrients/report/nutrientsfrm?max=25&offset=0&totCount=0&nutrient1=418&nutrient2=&nutrient3=&subset=0&fg=&sort=c&measureby=m.

United States Department of Agriculture [USDA]. 2012. Nutrition standards in the national school lunch and school breakfast programs. Final rule. 7 CFR parts 210 and 220. Fed. Regist. 17: 4088-4167.

United States Department of Agriculture [USDA]. 2015. Breaded products. 9 CFR part 381. Fed. Regist. 166.

Van Itallie, T. B. 1978. Dietary fiber and obesity. The American journal of clinical nutrition 31:S43-S52.

Van Soest, P. u., and R. Wine. 1967. Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell-wall constituents. Journal of AOAC international 50:50-55.

Verma, A., B. Sharma, and R. Banerjee. 2009. Quality characteristics and storage stability of low fat functional chicken nuggets. Fleischwirtsch Int 24:52-57.

Verma, A. K., and R. Banerjee. 2010. Dietary fibre as functional ingredient in meat products: a novel approach for healthy living—a review. Journal of food science and technology 47:247-257.

Verma, A. K., B. Sharma, and R. Banerjee. 2010. Effect of sodium chloride replacement and apple pulp inclusion on the physico-chemical, textural and sensory properties of low fat chicken nuggets. LWT-food science and technology 43:715-719.

Wang, H., P. Lim, M. Kao, E. Chan, L. Lin, and N. Wang. 2001. Use of isomalto-oligosaccharide in the treatment of lipid profiles and constipation in hemodialysis patients. Journal of renal nutrition 11:73-79.

Warren, F., B. Zhang, G. Waltzer, M. J. Gidley, and S. Dhital. 2015. The interplay of α-amylase and amyloglucosidase activities on the digestion of starch in in vitro enzymic systems. Carbohydrate polymers 117:192-200.

Wolever, T., J. Fernandes, and A. V. Rao. 1996. Serum acetate: propionate ratio is related to serum cholesterol in men but not women. The journal of nutrition 126:2790-2797.

Xiong, Y., X. Lou, C. Wang, W. Moody, and R. Harmon. 2000. Protein extraction from chicken myofibrils irrigated with various polyphosphate and NaCl solutions. Journal of food science 65:96-100.

Yang, C., and T. Chen. 1979. Yields of deep-fat fried chicken parts as affected by preparation, frying conditions and shortening. Journal of food science 44:1074-1076.

Zielinski, G., J. W. DeVries, S. A. Craig, and A. R. Bridges. 2013. Dietary fiber methods in Codex Alimentarius: Current status and ongoing discussions. Cereal foods world 58:148-152.

APPENDIX A

PRELIMINARY EXPERIMENTS

Appendix A-1 Formulas of Preliminary Experiment One

	10% brine			20% brine		
Ingredients	Control1	K4M1	K100M1	Control2	K4M2	K100M2
Meat	90.91%	85.91%	85.91%	83.33%	78.75%	78.75%
Water	8.09%	7.59%	7.59%	15.67%	14.75%	14.75%
Salt	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
Phosphate	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
METHOCEL K4M	0%	5.50%	0%	0%	5.50%	0%
METHOCEL K100M	0%	0%	5.50%	0%	0%	5.50%

Appendix A-2 Formulas of Preliminary Experiment Two

Ingredients	Control	K4M	K100M	Vita powder	Vita liquid
Meat	90.91%	86.80%	86.80%	85.91%	87.02%
Water	8.09%	7.68%	7.68%	7.59%	7.70%
Salt	0.50%	0.50%	0.50%	0.50%	0.50%
Phosphate	0.50%	0.50%	0.50%	0.50%	0.50%
METHOCEL K4M	0%	4.52%	0%	0%	0%
METHOCEL K100M	0%	0%	4.52%	0%	0%
VitaFiber^{TM} powder	0%	0%	0%	5.49%	0%
VitaFiber^{TM} liquid	0%	0%	0%	0%	4.27%

Appendix A-3 Formulas of Preliminary Experiment Three

Ingredients	Control	Combo1[1]	Combo2[2]	Combo3[3]	Combo4[4]
Meat	90.91%	84.76%	85.77%	84.76%	85.77%
Water	8.09%	7.48%	7.58%	7.48%	7.58%
Salt	0.50%	0.50%	0.50%	0.50%	0.50%
Phosphate	0.50%	0.50%	0.50%	0.50%	0.50%
METHOCEL K4M	0%	1.76%	1.76%	0%	0%
METHOCEL K100M	0%	0%	0%	1.76%	1.76%
VitaFiber™ powder	0%	5.00%	0%	5.00%	0%
VitaFiber™ liquid	0%	0%	3.89%	0%	3.89%

[1] Combo1: 30% METHOCEL K4M and 70% ViataFiber™ powder
[2] Combo2: 30% METHOCEL K4M and 70% ViataFiber™ liquid
[3] Combo3: 30% METHOCEL K100M and 70% ViataFiber™ powder
[4] Combo4: 30% METHOCEL K100M and 70% ViataFiber™ liquid

Appendix A-4 Formulas of Preliminary Experiment Four

Ingredients	Control	Combo1[1]	Combo2[2]	Combo3[3]	Combo4[4]
Meat	90.91%	84.76%	84.76%	84.59%	84.59%
Water	7.66%	7.05%	7.05%	7.03%	7.03%
Salt	0.78%	0.78%	0.78%	0.78%	0.78%
Phosphate	0.65%	0.65%	0.65%	0.65%	0.65%
METHOCEL K4M	0%	1.76%	0%	0.88%	0%
METHOCEL K100M	0%	0%	1.76%	0%	0.88%
VitaFiber™ powder	0%	5.00%	5.00%	6.07%	6.07%

[1] Combo1: 30% METHOCEL K4M and 70% ViataFiber™ powder
[2] Combo2: 30% METHOCEL K100M and 70% ViataFiber™ powder
[3] Combo3: 15% METHOCEL K100M and 85% ViataFiber™ powder
[4] Combo4: 15% METHOCEL K100M and 85% ViataFiber™ powder

Appendix A-5 Results and Discussion

Four successive experimental units were conducted to determine the formulation of chicken nuggets. Brine level (10% or 20%), type pf hydroxypropyl methylcellulose (HPMC) product (METHOCEL K4M or K100M), type of isomalto-oligosaccharide (IMO) product (VitaFiber™ powder or liquid), salt concentration (0.50% or 0.60%) and

fiber composition (15% HPMC and 85% IMO or 30% HPMC and 70% IMO) was determined by the sensory evaluation in texture and flavor by lab colleagues. The formulations of chicken nuggets from four experiments units were presented in Appendix A-1, A-2, A-3 and A-4. In Experiment One, all the chicken nuggets incorporated with HPMC product were unacceptable due to gummy texture no matter of the type of HPMC product and the level of brine. Therefore, brine level was kept at 10% that was common level used in the industry, and IMO product, which didn't cause the gummy texture and also kept a high level of fiber supplementation, was introduced into Experiment Two. While the chicken nuggets only supplemented with IMO products had a slimy texture problem. So in Experiment Three, a combination of 30% HPMC product and 70% IMO product was tested. The chicken nuggets added with the liquid source of IMO product still had the slimy texture issue. For this reason, IMO product was determined as the powder source one. A sweet taste was also tasted from the treatment nuggets. In Experiment Four, to determine the best composition of HPMC products and IMO product, two kinds of proportions (30:70 and 15:85) were compared and a higher salt concentration (0.60% of final product) was applied to cover the sweet taste. The chicken nuggets incorporated with 30% METHOCEL K100M and 70% ViataFiber™ powder was the most similar to the control. In a conclusion, the best fiber composition of treatment chicken nuggets was 30% HPMC product (METHOCEL K100M) and 70% IMO product (VitaFiber™ powder), also with addition of 10% brine containing 0.60% salt and 0.50% phosphate of final product.